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ABSTRACT

This document is the second of a three-volume teacher resource book for use with the Energy 80 energy education program. The program is designed to enhance students' understanding of energy, either through supplements to traditional courses, such as mathematics, science, social studies, or homemaking, or by developing a mini-course or interdisciplinary course in energy. Although written for middle/junior high school students, many of the activities are useful for high school and upper elementary grades. Included are 27 activity sheets, 33 worksheets, 1 reading, and 7 overhead transparency masters for use with units on energy fundamentals (energy flows; measuring energy; energy efficiency) and energy flows in nature (wind/water cycles; photosynthesis; respiration; food chains/webs; energy in the U.S. food system; and origin of fossil fuels as food energy). General objectives for each unit, lesson plans related to each topic/activity, instructional strategies, and background information for teachers are also included. (JN)

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TEACHING VOL. 2 ABOUT ENERGY

1983

Units 1 and 2 of the **Energy 80** Resource Book

Enterprise for Education, Inc.
Santa Monica, California

1. Energy Fundamentals
2. Energy Flows in Nature

112 pages of
Reproducibles:
27 activity sheets
33 worksheets
1 reading
7 overheads

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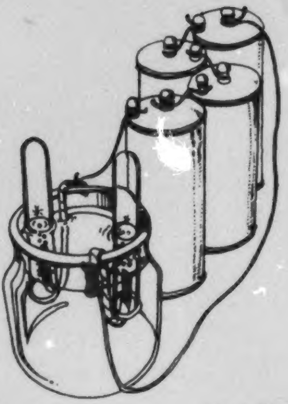

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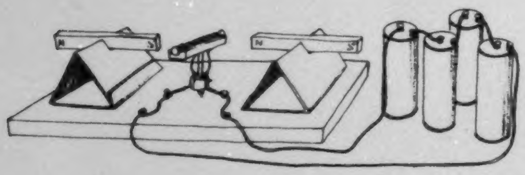

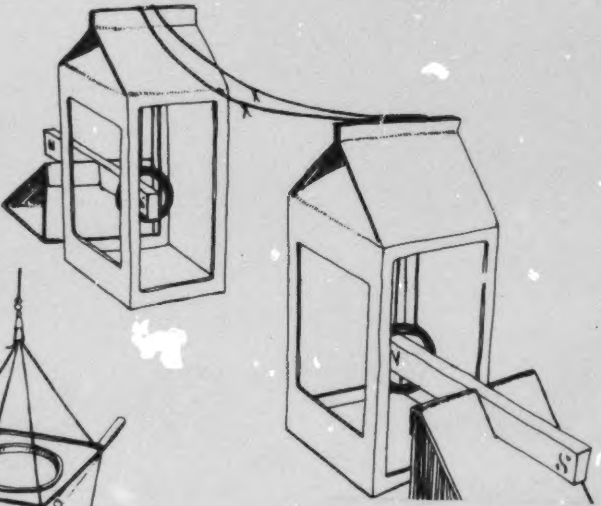

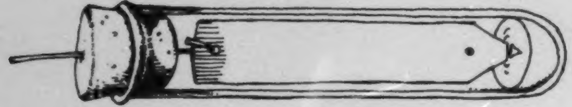

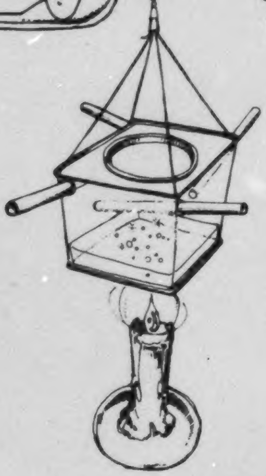

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TEACHING ABOUT ENERGY

VOL. 2

Units One and Two

1983

The Energy 80 Resource Book

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Unit One
Energy Fundamentals

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Why We're Teaching This

The major improvement in human material welfare ("progress") that began in Europe several centuries ago originated, at least in large part, in a series of mental tools and attitudes that we associate with the culture of "science and technology." Some of the most prominent of these tools and attitudes are:

- a conviction that there exist discoverable "laws of nature" that are predictive.
- an urge to measure, to express attributes in numbers so that relations can be stated mathematically ("quantification").
- an engineering urge, a desire to create machines and systems that approach ever more closely to some ideal, such as energy efficiency.

All of these are **human** pursuits, just as much as composing symphonies and raising children are. They happen to be a set of pursuits that have proven extraordinarily powerful in dealing with the physical world, sometimes to our great disadvantage, but usually to our benefit.

In this unit, we will try to develop the students' abilities to use these cultural tools in the field of energy.

For example:

- We would like students to be able to see how the laws of thermodynamics describe what they see going on around them, and to use those laws in imagining fresh possibilities.
- We would like students to deal quantitatively with the energy in their lives, connecting the dollars and cents, the Btu's, and the R-values of their home insulation, for example.
- We would like students to help us make the technical and lifestyle innovations necessary to release us from our present energy quandary.

The content of this unit is largely drawn from the discipline of physics. These are not the only understandings one needs to think about possible energy futures, but they are essential and, we believe, fundamental to any rational discussion of any aspect of the energy situation.

What We'll Teach and How

RECOGNIZING ENERGY. We begin by reviewing the existence of energy, its forms, and the fact that it cannot be made. Our prinicipal means for fixing the concept that energy flows from form to form but is not made is an open-ended series of activities in which students convert energy from one form to another.

MEASURING ENERGY. Beginning with units of heat (the calorie and Btu), we define units through activities, progressing to other forms of energy. As forms can be interchanged, so can units, and we do this in a few bizarre calculations. (How many horsepower-hours in a chocolate sundae?)

MEASURING ELECTRICITY. Because electrical units are more abstract, we approach them separately, beginning by examining appliance nameplates in the home, then developing amperes, watts, and volts in classroom calculations. Knowledge of the units leads to learning to read gas and electric utility meters and bills, and we begin to compile records on household consumption for study later in the course.

EFFICIENCY. In our conversions, we have noted that we don't always get what we want. Now, using our ability to measure energy, we measure inputs and outputs and establish the concept of first-law efficiency. Comparing gas-fired and electric water heaters reveals the importance of considering the entire system and not just a component. Finally, we see how first-law efficiency may be misleading and develop the concept of "second-law efficiency."

Objectives

Within the lesson plans, the "Objectives" are stated as generalizations. Stating them in that form enables teachers reading the lesson plan to quickly grasp what the lesson is about. The major generalizations are summarized below.

For evaluation, however, it is necessary to specify some observable act of the student which a reasonable person would be willing to accept as evidence that the student understood the generalization. (Repeating the generalization, of course, isn't such an act; parrots can do that.) A set of these operationally-defined objectives is given below. Ideally, each specifies the conditions under which the student acts and the action, as well as what level of performance is to be considered adequate, if that is not obvious. Actions have been restricted to those which could be performed in a classroom test.

To avoid making the objectives even longer than they now are, language is used which could not be used with students. These objectives will probably be of most use in preparing tests.

The Big Ideas

Energy exists in different forms.

Energy can change from one form to another.

All human use of energy involves changing it from one form to another.

Energy is not lost in any transformation, but in almost every energy conversion part of the energy is converted to heat.

Energy cannot be created or destroyed.

Energy can be measured.

A measurement of a quantity of energy in one form can be expressed as an equivalent amount of energy in another form.

The efficiency of a device or process is the ratio of the energy obtained in the desired form to the energy supplied.

Some energy flows are irreversible.

It is impossible to convert all of a quantity of heat to work.

Sources of energy which are rich in available work are more useful than those poor in available work, joule for joule.

Objectives

Objectives with the same number (e.g., 1A, 1B, 1C) reflect understanding of roughly the same generalization. The most basic objectives are marked with an asterisk. An asterisk on item A in a series of alternatives applies to the entire series, not just to the first alternatives.

Energy Transformations/First Law

Energy Exists in Different Forms

*1A. Given an illustration of a change occurring, the student identifies at least one form of energy evident.

1B. Given a written description of a change, the student identifies at least one form of energy present.

2A. Given a list of items all of which are forms of energy except one, which is a substance, the student identifies the item which is not a form of energy.

2B. Given a list of items all of which are substances except one, which is a form of energy, the student identifies the item which is a form of energy.

Energy Can Be Converted from One Form to Another

1A. Given two forms of energy, the student specifies at least one device or method that can transform the first form to the second. (Forms chosen from: light, motion or kinetic energy, chemical energy, thermal energy, electrical energy.)

1B. Given the name of a device or natural process familiar to the student, the student identifies at least one form of energy which is supplied to the device or process, and at least one form of energy to which the supplied energy is converted by the device.

Energy Cannot Be Created or Destroyed

*1A. Given descriptions of several machines, one of which is a perpetual motion machine which provides a net output of energy (for example by turning a shaft to which other machinery is connected) and which has no energy inputs, the student selects the perpetual motion machine as the one which is not feasible.

1B. Given measurements of two energy inputs to a device during a process, the stipulation that at the end the internal energy of the device is the same as it was at the start of the process, and asked to identify the sum of the energy outputs at the end of the process, the student chooses from a selection the amount equal to the sum of the inputs. (All measurements in the same units.)

1C. The student recognizes that the amount of energy (energy/mass) in the universe is constant.

Heat

1. The student characterizes thermal energy as a form of kinetic energy.

2. Given a description of a process in which the average random speed of the molecules of a body is increased, the student states that the temperature of the body has increased.

3. Given two containers of water at the same temperature containing different volumes of water, the student recognizes that a greater quantity of heat can be transferred from the container with the greater volume of water.

4. Given descriptions of systems in each of which heat flows from a source to a sink at a lower temperature, with the systems identical except for differences in the temperatures of the sources and sinks, and the temperatures of all sources and sinks given in degrees Celsius, the student chooses the system having the greatest temperature differential as the one in which the rate of heat flow will be greatest.

5. Given a description of a moving object coming to rest because of friction, the student states that kinetic energy has been converted to thermal energy.

6. Given a description of a situation in which heat flows between two bodies in a vacuum, from the three heat flow mechanisms the student chooses radiation as the primary method of transfer in this case.

7. Given a description of a situation in which heat flows between two bodies in a vacuum, separated by a mirror, and connected by a thick U-shaped body, from the three heat flow mechanisms the student chooses convection as the primary method of transfer in this case.

8. Given a description of a situation in which heat flows between two bodies in a vacuum, separated by a mirror, and connected by a U-shaped body, from the three heat flow mechanisms the student chooses conduction as the primary method of transfer in this case.

Electrical Energy

1. Given a list of familiar materials, the student identifies metals as good conductors of electricity, and glass, plastics, and ceramics as poor conductors.

2. Given realistic illustrations of several wiring set-ups, only one which contains a completed circuit, the student identifies the set-up with the completed circuit as the only one in which electricity is flowing.

3. Given an illustration each showing a wire and a number of compasses in a plane perpendicular to the wire, in one of which all compasses point in the same direction and in the other perpendicular to a radius drawn from the wire, the student identifies the first case as the one in which an electric current is flowing.

4. The student recognizes that a magnetic field is created around a wire through which a current is flowing.

5. Given a drawing of magnets with poles in various positions and all poles labelled either N or S, the student identifies those situations in which the poles are attracting each other and those in which they are repelling each other.

Light

1. The student recognizes that when an object absorbs light, it is warmed. (The differing emissivity and absorptivity of various surfaces is treated in Unit Five.)

2. The student recognizes that some forms of light are not visible to the human eye.

3. Given a set of objects with temperatures above absolute zero, the student recognizes that all of the objects emit radiation.

Potential Energy

1. The student recognizes that work and heat exist only during their performance/transfer; others are either kinetic energy of potential energy, such as chemical energy and the potential energy of water in a reservoir.

Measuring Energy

Reading Graduated Scales

1. Given an illustration of a linear graduated scale with every tenth graduation longer, each long graduation labelled with a multiple of ten, and an arrow pointing to one of the shorter graduations, the student gives the measurement indicated by the arrow, correct to the nearest marked division.

2. Given an illustration of a linear graduated scale with every fifth graduation longer, each long graduation labelled with a multiple of ten, and an arrow pointing to one of the shorter graduations, the student gives the measurement indicated by the arrow, correct to the nearest marked division.

3. Given an illustration of a linear graduated scale with every fifth graduation longer, each long graduation labelled with a multiple of ten, and an arrow pointing to a point three-quarters of the distance between two of the shorter graduations, the student gives the measurement indicated by the arrow, correct to the nearest marked division.

4. Given an illustration of a graduated scale on an arc, with every fifth graduation longer and marked in a multiple of ten, and with a pointer resembling those used on panel meters of the quality used in schools, the student gives the measurement indicated by the pointer, correct to the nearest marked division.

Significant Figures

1. Given two measurements each integers containing 3 significant figures (avoiding the combination of 5 and 2 as the least significant digits), a definition of a third quantity as the product of the two measurements, and a list of possible values for the third quantity containing from 1 to 5 figures, the student selects the value which contains 3 figures.

Graphs

1. Given a table containing ordered pairs of numbers arranged in two labelled columns, and coordinate paper with preprinted axes labelled in units that match the column headings, the student constructs a graph on Cartesian coordinates.

2. Given a graph on Cartesian coordinates with axes labelled with units of measurement, and an x or y value in the units shown on the graph, the student finds the corresponding y or x value, including labelling it with the proper unit of measurement.

Heat Energy Can Be Measured

1A. Given a liquid-in-column thermometer, the student reads the temperature of air or water correct to the nearest marked division.

1B. Given a realistic illustration of a liquid-in-column thermometer, the student reads the temperature of air or water correct to the nearest marked division.

2A. Given a quantity of water and a glass graduated cylinder, the student reads the volume of water correct to the nearest marked division. (No correction for holds/delivers required.)

2B. Given a realistic illustration of a graduated cylinder containing water, showing a meniscus, the student reads the volume of water correct to the nearest engraved division. (No correction for holds/delivers required.)

3. Given the volume in milliliters of a quantity of water, the student states the approximate mass of the water in grams.

4. Given the mass in grams of a quantity of water and a temperature rise in degress Celsius, the student calculates the heat transferred in calories. (No correction for temperature or pressure required.)

5. Given measurements of the energy available from combusion of each of two samples of substances, the measurements having identical numerical values but with one in calories and the other in Calories, or calories and food calories, the student states that the quantity of energy available from the sample whose measurement is in Calories is 1000 times more than the quantity available from the other sample.

*6. Given the mass in pounds of a quantity of water and a temperature rise in degrees Fahrenheit, the student calculates the heat transferred in Btu's. (No correction for temperature or pressure required.)

Electrical Energy Can Be Measured

*1. Given an electrical home appliance, the student finds th[illegible]ng plate and makes from it a correct written record of the voltage, amperage, and wattage ratings.

2. The student recognizes that power is proportional to the product of volts and amperes, and that watts are a measure of power.

3. Given watts and volts, the student calculates the amperes drawn by the appliance.

4A. Given the consumption in amperes of each appliance in a set of appliances, the student specifies whether any particular combination would cause a fuse of a given amperage to blow (or a circuit breaker of a given amperage to trip).

4B. Given the amperage of a number of separate devices, the student calculates the amperage of all operating together.

5. Given the wattage of an appliance and the number of hours of operation, the student calculates correctly the electrical energy consumed, and states that the result is in watt-hours or kilowatt-hours, as appropriate to the numerical value of the student's result.

6. Given a measurement in watts, the student converts the measurement to kilowatts.

7. Given kilowatts consumed (or generated) and the number of hours of consumption (or generation), the student calculates the kilowatt-hours consumed (or generated).

8. Given kilowatts or watts consumed (or generated) and the length of time during which consumption or generation took place, measured in any unit except hours, the student calculates the amount of electricity consumed (or generated) in kilowatt-hours.

Work Can Be Measured

1. Given a mass in kilograms and its acceleration in meters per second, the student calculates the force applied in the direction of motion. and states that it is in newtons.

2. Given a force in newtons and the distance through which the force travels in meters, the student calculates work, and states that the result is in joules.

3. Given a situation in which a simple machines is employed to reduce the rate at which energy is being supplied, the student recognizes that the amount of work performed with and without the use of the device is the same.

Utility-Supplied Energy Is Measured

1. Given a choice of various units of measurement, including the kilowatt and kilowatt-hour, the student identifies the kilowatt-hour as the unit by which electricity is commonly sold.

2. The student identifies the cubic foot as the unit commonly used to measure natural gas entering the home, and the therm as the unit commonly used to measure the quantity of energy sold in the form of gas.

3. Given an illustration of a meter dial with the pointer midway between two numerals, the student recognizes that the dial is indicating the lesser of the two numerals.

4. The student is given an illustration of two meter dials, the one on the left having clockwise numerals and the pointer exactly on one of the numerals, and the one on the right having counter-clockwise numerals. If the pointer on the right dial is between 1 and 0, the student reads the dials as the numeral on which the left hand point rests followed by a zero. If the pointer on the right dial is between 9 and 0, the student reads the dials as one less than the numeral on which the left hand pointer rests, followed by nine.

5. The student is given an illustration of two meter dials, the one on the left having counter-clockwise numerals and the pointer exactly on one of the numerals, and the one on the right having clockwise numerals. If the pointer on the right dial is between 1 and 0, the student reads the dials as the numeral on which the left hand point rests followed by a zero. If the pointer on the right dial is between 9 and 0, the student reads the dials as one less than the numeral on which the left hand pointer rests, followed by nine.

6. The student reads a common pattern of electric watt-hour meter or gas meter, as shown by a realistic illustration of its dials. The most difficult case is to be used, which is taken to be two examples in conjunction: a) the pointer is on a numeral on a clockwise rotating dial, and the pointer on the dial to the right is between 0 and 9, and b) the pointer is on a numeral on a counter-clockwise rotating dial, and the pointer on the dial to the right is between 9 and 0.

7. The student identifies the meaning of all items appearing on the forms of utility bill used in the student's community.

8. Given a rate in cents per kilowatt-hour, appliance amperage, and hours of operation, the student can calculate the cost of the electricity consumed in operating the appliance.

9. Given a number of graphs of time against amount of energy consumed for day, week, and year, the student identifies the pattern which most closely resembles that of the student's own household.

Comparisons of Energy Units

1. Given a conversion factor stated as 1 X-unit = n Y-units, the student converts an energy measurement in X-units to Y-units.

2. Given a conversion factor stated as one X-unit = n Y-units, the student converts an energy measurement in Y-units to X-units.

3A. Given a measurement of power and a list of other units, one of which measures power and the rest energy, the student indicates the power unit as the only one to which the given measurement could be converted.

3B. Given a measurement of energy and a list of other units, one of which measures energy and the rest of which measure power, the student chooses the energy unit as the only one to which the given measurement could be converted.

4. From a list of energy-related units of measurement, the student can separate those which are customary from those which are SI. (The calorie is to be included among non-customary units).

Efficiency and Energy Quality

Rejected Heat is Produced in Most Energy Transformations

*1. Given a series of familiar macroscopic energy transformations, the student recognizes that heat is produced in each of the transformations.

First-Law Efficiency

*1. Given the energy input to a device and the energy transferred in the desired form by the device, the two quantities expressed in the same units of measurement, the student calculates the efficiency of the device and expresses it as a percentage.

2. Given the efficiency of a device and the energy output required, the student calculates the energy input required.

Systems Efficiency

1. Given one device in a familiar system through which energy flows, the student correctly identifies at least two other components of the system.

2. Given the efficiency of each component of a system, expressed as percentages, the student calculates correctly the system efficiency. (Limit the number of components in the system to not more than five.)

Heat Engines

1. Given a description of several devices, all but one of which are heat engines, the student chooses the device which is not a heat engine.

2. Given a description of a heat engine, the student identifies the source and the sink.

Objectives

Second Law of Thermodynamics

1. Given descriptions of several systems, in one of which heat flows from cold to hot and in the rest from hot to cold, the student identifies the cold to hot flow as impossible.

2. Given descriptions of several machines, one of which is a perpetual motion machine of the second kind, the student selects the perpetual motion machine as the one which is not feasible.

Theoretical and Practical Efficiencies

1. Given descriptions of two or more heat engines with differing source and sink temperatures and asked to select the one with the highest theoretical efficiency, the student selects the one with the greatest temperature differential.

2A. The student recognizes that there exists a theoretical limit on the conversion efficiency of any given energy conversion process, such that this limit cannot be exceeded.

2B. Given two percentages and that one is the theoretical and the other the practical efficiency of an imaginary device, the student identifies the smaller percentage as the practical efficiency.

Energy Quality

1. Given temperatures obtainable with two energy sources, the student states that a greater percentage of the energy in the higher temperature source can be converted to work.

Energy Forms and Transformations

Objectives

This lesson contributes to students' understanding of the following concepts:

Energy occurs in different forms.

Energy can be transformed from one form to another.

Energy cannot be created or destroyed.

Some energy exists as potential or latent energy.

Format of the Lesson

Recognizing energy

Identifying some forms of energy

Mini-investigations: energy changes form

Stored energy

Homework chart

Materials Needed

candle

rubber bands at least one-half inch wide. A suitable choice is No. 84 bands (3½" x ½"), one-quarter pound of which costs about $1.80 and contains about 52 bands. To save the bands for reuse next year, wash them in warm soapy water and, after they are thoroughly dry, dust them with plain talc.

clockwork toy

worksheet **Energy Conversions.**

Recognizing Energy

Ask the class what is in the universe. Students will generally begin to name things. List some of these in a column on the board; write "matter" as a heading to this list of things. (If any forms of energy are mentioned, list them in a separate column.) Summarize by asking the class if we could just say that there is **matter** in the universe, since all (or most of) the things named are matter.

What is there besides matter in the universe? What else can we observe? (Some of the answers may reflect spiritual insights; disqualify yourself from discussing these by stating that, right now, we only want to discuss things we can measure.)

If the students have suggested any forms of energy (which you have listed in a separate column), elicit similiar answers, and discuss each proposed addition. Some may be different names for the same thing.

If no one volunteers any form of energy, light a candle. Ask students what they can observe. Is everything they observe matter? What about the light? Is there light in the universe?

On the board, list each form of energy that the students think of. A conventional list of six, well-suited to our purposes, would be:

light (radiant energy, electromagnetic waves)

electricity

heat

motion (mechanical energy, kinetic energy)

chemical energy

nuclear energy

It isn't necessary to flog all six out of the students at this point; you can add others as the lesson, or year, goes on.

Put "Forms of Energy" as a heading to this list.

Teacher Background on Forms Of Energy

The above list has been chosen for teaching purposes, taking into account the students' probable previous learning and experience, and is not meant as the scientist's last word on forms of energy. For example, heat, as we will discuss later, is related to molecular motion, and so we could classify it as motion. However, combining heat and motion at this point only baffles students.

Energy Changes Form

Tell the students that energy has the ability to change form, and that is happening all around us. For example, ask the students to wave their hands back and forth. What kind of energy is shown? (ANS: Motion.) Ask the students to continue waving their hands back and forth, but with their hands put together. Some of the motion is being transformed into another kind of energy. What? (ANS: Heat.)

Energy is Conserved

Wind up the clockwork toy and let it move. Ask students to describe where the mechanical energy of the toy comes from? Why does the toy finally stop moving? Summarize that we can only get out as much energy as we put in. Energy cannot be made. On the other hand, it can't be destroyed, either.

Stored Energy

Lift a heavy object off the floor and put it on the edge of a table. It took mechanical energy to lift the object. Where did the mechanical energy go? It is stored in the object's position. We call this, potential energy. The object might fall. There are other forms of stored energy. Chemical energy is one.

Strike a match and light a candle. Ask the students to describe the energy transformations that occurred. (ANS: Chemical energy [in teacher] to motion, to heat [friction of matchhead]. Chemical energy [in matchhead] to heat and light. Chemical energy [in candle] to heat and light. And there are others.)

The Need for Measurement

Give each student a rubber band. Ask them to stretch the rubber bands quickly and then feel them with their lips. Does anything happen?

Usually, there will be disagreement. Some will say the band got warmer; others that it didn't. Point out that it is very reasonable to be uncertain whether the band got warmer. Our senses are not always a trustworthy guide, especially to temperature. How else can we measure temperature? (ANS: With a thermometer.) Agree that is true, and a sensitive thermometer would show the band did become warmer. Where did this thermal energy come from? (ANS: From the work we did stretching the band.)

Homework Assignment

Tell the class that we will be spending some time investigating energy, and outline the scope of the unit you plan. Identify and stress the sorts of activities the students will have a chance to do.

Pass out the **Energy 80** booklets and ask the students to complete the first page, and read the two pages, "In all the universe . . . ."

At this point, consider whether you wish to send home a letter to parents, as discussed in the section, "Protecting Privacy," in the **Introduction.**

Pass out the worksheet. Discuss it in class. Have students volunteer a few answers and allow the others to use these, if they wish, in completing the form.

Energy Transformations

Worksheet

Energy can be converted from one form to another. We often need to do this when we use energy.

In each of the empty boxes below, write the name of a device or method that could convert energy from the form named on the left side to the form named at the top. An example is done for you. Some of the answers are easy; some are hard. Do as many as you can.

To This Form of Energy

How to Convert This Form of Energy

	heat	motion	light	electricity	chemical	nuclear
heat	▨					
motion		▨				
light			▨			
electricity			light bulb	▨		
chemical energy					▨	
nuclear energy						▨

Typical Answers to the worksheet

Motion to heat: friction
Light to heat: solar collector
Electricity to heat: electric blanket, electric room heater
Chemical energy to heat: burning anything, respiration in living things
Nuclear energy to heat: power reactor, atomic bomb

Heat to motion: automobile engine, steam engine, gas turbine
Light to motion: radiometer
Electricity to motion: electric motor
Chemical energy to motion: dynamite
Nuclear energy to motion: atomic bomb

Heat to light: light bulb
Motion to light: sparks struck from a flint
Chemical energy to light: match, fire, glow from a firefly
Nuclear energy to light: atomic bomb

Heat to electricity: thermopile
Motion to electricity: generator
Light to electricity: solar cell
Chemical energy to electricity: battery
Nuclear energy to electricity: nuclear power plant

Heat to chemical energy: making water gas (Carbon monoxide and hydrogen) from red-hot coke
Motion to chemical energy: no familiar example
Light to chemical energy: photosynthesis
Electricity to chemical energy: charging a battery, electrolysis of water to make hydrogen, electrolytic production of aluminum
Nuclear energy to chemical energy: no familiar example

Nuclear energy comes from the conversion of mass into energy. Because matter and energy are equivalent ($E = mc^2$), energy can also be converted into mass. For example, the mass of a body increases in proportion to its kinetic energy. This relation also holds for all other forms of energy, but there are no familiar examples of such processes.

Heat to nuclear energy: see note above
Motion to nuclear energy: see note above
Light to nuclear energy: see note above
Electricity to nuclear energy: particle accelerator (the mass of the accelerated particle is measureably increased).
Chemical energy to nuclear energy: see note above

Why Energy Is NOT "the Ability to Do Work"

This is a plea not to begin your students' study of energy with the old definition, "energy is the ability to do work." Here are a few reasons why we think doing so is counterproductive.

1. Most students don't know what a physicist means by "work," which is very different from its everyday meaning. A recent article in a social studies journal included a lesson plan in which a child's holding up a book with an out-stretched arm was described as work. It may be tiring; it may fit the student's idea of work; but it is not work as the physicist means it in the definition. If the students don't understand what work is, then the dictionary definition of energy is meaningless.

2. Good definitions of energy (good for teaching purposes, we mean) are scarce because most definitions describe a thing in terms of other things that are more fundamental. What is more fundamental or elemental than energy? The best alternate definition we have heard is that energy is the capacity to produce change. But we feel proceeding from this is more confusing than proceeding from the students' experience.

3. Heat is a form of energy. To convert this heat to work, however, always requires access to some reservoir at a still lower temperature. As a practical matter then, the energy that is arguably most important to us, the substantial amount of heat represented by the ambient temperature, is not "able to do work."

4. Beginning instruction with definitions is, in itself, pedagogically suspect unless the definitions can be shown to have some operational necessity. It is difficult to see how knowing this definition will have any effect on the students' progress. We think there is no need for a definition.

Notes

Changing Electricity to Light

Objectives

This lesson contributes to students' understanding of the following ideas:

The incandescent light bulb converts electrical energy to heat and light.

Electricity heats materials it passes through.

When energy is converted from one form to another, part is lost as heat.

Format of the Lesson

Discussion of light bulbs

Making light bulbs

Vocabulary

incandescence
incandescent
filament

Materials Needed

clear incandescent light bulb in a receptacle.

dimmer

For the light bulb:

picture hanging wire finely stranded. Use the lightweight sizes, not the sizes for hanging heavy pictures. A suitable type is Anchor Wire Corp stock #41250, Size no. 1 Braided Picture Wire. Cut the wire into pieces about 10 cm long and have the students unbraid or untwist the wire to obtain single strands. Being iron, this wire has a much higher resistance than copper wire. Twenty-five cents worth is enough for hundreds of students.

golf tees or nails or pencils, for forming the filament. Golf tees work best.

modeling clay a silver-dollar-sized chunk for each student.

solid copper wire 18 gauge and insulated, enough to give each student two pieces about 30 cm long. Available in hardware or electrical supply stores at about 6¢ a foot.

clear plastic medicine cups or the clear plastic closures that come on some brands of aerosol whipping cream, or very small glass jars, such as baby-food jars.

source of electric power this activity draws a lot of current. Although 6-volt batteries will work with some filaments, 9- or 12-volt batteries are more certain to give satisfactory results. A bank of #6 cells can be used, or use lantern or "hot-shot" batteries. There is no danger of shock from such batteries, but they are expensive (about $10) and will last only one year.

worksheet. **Making a Light Bulb,** one per student.

Preliminary Discussion

Show students a clear incandescent bulb. Ask what it is and what it does. (ANS: Light bulb. It converts electricity to light.)

If you have a dimmer available, it is helpful to turn the bulb on gradually. (Actually, it will pop on, then, as the filament becomes warmer and its resistance changes, you can back off the voltage a bit without the light going off.) Ask if anyone knows the name of the part that glows. (ANS: Filament.) Gradually increase the voltage with the dimmer and ask the class to describe what happens. (ANS: The light gets brighter and less red, more white.)

Ask students if they have ever seen anything heated red-hot by a torch. What happens? (ANS: It first gets just dull red, then brighter and brighter.)

The name we give to the process of heated objects giving off light is incandescence. So, in an incandescent light bulb, how is the light produced? (ANS: By heating the filament with electricity.)

Leave the incandescent bulb and dimmer where students can examine them after class. You may wish to post the diagram of an incandescent bulb nearby, so students can identify its many parts and appreciate their purposes.

Announce that the class is going to try to make its own light bulbs. Pass out the worksheets and materials.

Making Light Bulbs

This is a simple, easy to understand activity that students generally enjoy a lot — especially burning up filaments. Having an activity of this sort early in the course accustoms students to laboratory work and will make it easier to conduct later activities that are inherently more difficult.

You may wish to make one light bulb in advance yourself, to have a demonstrator students can examine. But we recommend you don't light yours until students have had a chance to try theirs.

Discussing the Light Bulbs

Talk about:

Besides light, what other kind of energy did the bulbs produce?

Why do you think they burnt out so much faster than commercial light bulbs do?

Suggest students may want to try to make more light bulbs on their own. "Projects for Independent Investigation" offers some suggestions on variables students might explore.

While having a student collect the leftover materials, summarize that we have succeeded in changing electricity to light. Can we change light to electricity?

Projects for Independent Investigation

1. How does changing the length of wire in the filament change the operation of the light bulb — for example, its brightness?

2. Who can make the longest-burning light bulb?

3. If you have an ohmeter, ammeter, or multimeter, measure the current consumption of different homemade light bulbs operated from the same voltage source. What accounts for the variations in current consumption?

4. Besides the incandescent light bulb, how many other electric light sources can you find in use in your neighborhood? Make a map for your class showing the types of sources and where they can be seen.

Making a Light Bulb

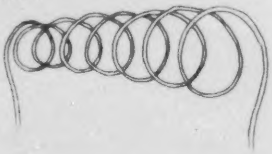
The incandescent light bulb has been in use since Thomas Edison introduced the first practical version in 1879.

Try to make a light bulb yourself. You will need:

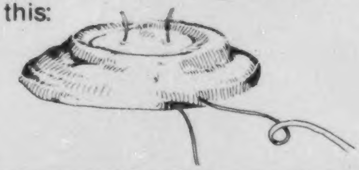
☐ wire for the filament
☐ wire for the connections
☐ a source of electricity, such as a dry cell battery
☐ a clear jar or cup
☐ modeling clay
☐ a nail, pencil, or golf tee for forming the filament

Do you have all the things you need?

Step One: The filament. Take a piece of iron picture-hanging wire about 10 cm long. Unbraid it until you get a single strand of wire (share the other strands with classmates). Wrap the wire around a golf tee to form a coiled filament. Leave 2 cm of straight wire at each end. It should look like this:

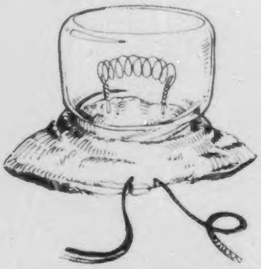


Step Two. The base: Flatten a piece of modeling clay big enough to cover the mouth of your jar. Stick the two bare ends of your connecting wires through the clay. The wires should be just as far apart as the filament is long. It should look like this:



Step Three: Finishing the bulb: Attach the filament to the wires by wrapping the filament wires around the connecting wires. Put the globe over the filament and press it to the base. Check to be sure that the filament wire is still touching the connecting wire, and the connecting wires don't touch each other anyplace.

Step Four: Connect your bulb to the battery. If it doesn't light by the count of 10, disconnect it and check your connections. Make sure the wires aren't touching under the clay.



Observations

1. Which part of the light bulb gives out light? ____________________

2. Is there evidence of any other form of energy besides light coming from the light bulb?

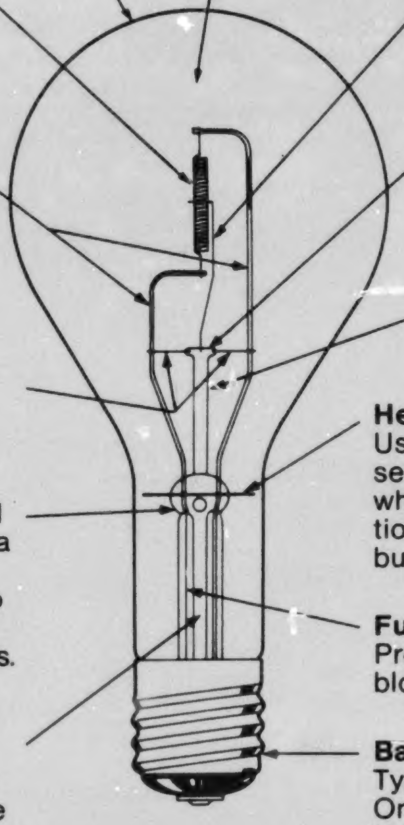
____

____

3. Trace the energy flow from a dry cell to a flashlight bulb. Four forms of energy should be listed.

____________ → ____________ → ____________ + ____________

4. About how many years has the incandescent light bulb been in use? ________



Bulb
Soft glass is generally used. Hard glass is used for some lamps to withstand higher bulb temperatures and for added protection against bulb breakage due to moisture. Bulbs are made in various shapes and finishes.

Filament
The filament material generally used is tungsten. The filament may be a straight wire, a coil, or a coiled coil.

Lead-in Wires
Made of copper from base to stem press and nickel-plated copper or nickel from stem press to filament, they carry the current to and from the filament.

Tie Wires
Molybdenum support lead-in wires.

Stem Press
The lead-in wires in the glass have an air-tight seal here and are made of a combination of a nickel-iron alloy core and a copper sleeve (Dumet wire) to assure about the same coefficient of expansion as the glass.

Exhaust Tube
Air is exhausted through this tube during manufacture and inert gases introduced into the bulb. The tube, which originally projects beyond the bulb, is then sealed off short enough to be capped by the base.

Gas
Usually a mixture of nitrogen and argon is used in lamps 40 watts and over to retard evaporation of the filament.

Support Wires
Molybdenum wires support the filament.

Button
Glass is heated during manufacture, and support and tie wires placed in it.

Button Rod
Glass rod supports button.

Heat Deflector
Used in higher wattage general service lamps and other types when needed, to reduce circulation of hot gases into neck of bulb.

Fuse
Protects the lamp and circuit by blowing if the filament arcs.

Base
Typical screw base is shown. One lead-in wire is soldered to the center contact and the other soldered or welded to the upper rim of the base shell. Made of brass or aluminum.

Typical Incandescent Lamp

Courtesy of GTE Sylvania

Changing Motion to Electricity; Changing Electricity to Motion

Objectives

This lesson contributes to students' understanding of the following concepts:

An electric motor converts electrical energy to mechanical energy.

The electric generator converts mechanical energy to electrical energy.

Magnetism is used in accomplishing this conversion.

Format of the Lesson

This lesson relies on a "gee-whiz" effect. We demonstrate a phenomenon that engages student interest, observe it closely while altering various variables, and then discuss what might be happening. Several sets of the apparatus needed for the demonstration can be constructed in class, if you have that many bar magnets; or you may wish to have an able student construct a set for you in advance as an individual project. It isn't hard to do; the picture on the activity sheet is enough explanation. The activity sheet also provides some guidance for a period of student puzzling over how the set works. It is important to provide "free time" for this puzzling. Some optional experiments are provided at the end of the lesson for classes who wish to examine in more detail how the set works; i.e., learn more about the relation between electricity and magnetism.

Materials Needed

(For each set of two swings)

bar magnets two. Available through scientific supply catalogs, around $7 a pair (Fisher 543034).

wire #28 magnet wire (100 feet). Available through scientific supply catalogs or electronic supply houses, about $8 a pound (616 meters).

milk cartons two empty 1/2 gallon cartons. Save from kitchen.

cardboard two pieces about 3" x 12" each.

masking tape

cylinder, to form coils. Can be a flashlight, cardboard tube, or olive bottle.

knife

The Apparatus

Please look at the picture on the activity sheet.

The electric motor-generator swing consists of two identical coils of wire, each suspended so that a bar magnet passes through the hole in the coil without touching the coil. The two coils are connected to each other. When mechanical energy (a moving hand) is used to set one coil into pendulum-like motion, the other coil starts to move, too!

The swing demonstrates the fundamental principles of both the electric motor and the electric generator, and shows why they have basically the same parts. An additional benefit is that introducing motors and generators this way doesn't require students to understand commutator switching, which can be a roadblock.

Basically, the apparatus works as follows: Whenever a wire moves through a magnetic field, the magnetic field pushes some electrons down the wire. That's what's happening in the coil we set in motion by hand. (Call it coil A.) The resulting electrical current flows through the wire to coil B. Whenever an electric current flows through a wire, it sets up a magnetic field around the wire. So, there is a magnetic field around coil B, with a north and south pole. This magnetic field interacts with the magnetic field of the bar magnet, attracting and repelling. As coil A changes the direction of its motion in respect to its magnet, the direction of the current in the wire changes. That reverses the magnetic poles of coil B, causing a change in the direction of its motion. So the two coil-pendulums swing together.

Sub-Investigations

Does moving the coil near the magnet generate electricity?

Connect the lead wires to a galvanometer and see. Also investigate the relationship between direction of motion and direction of current.

Is the coil of wire a magnet when electricty is flowing through it?

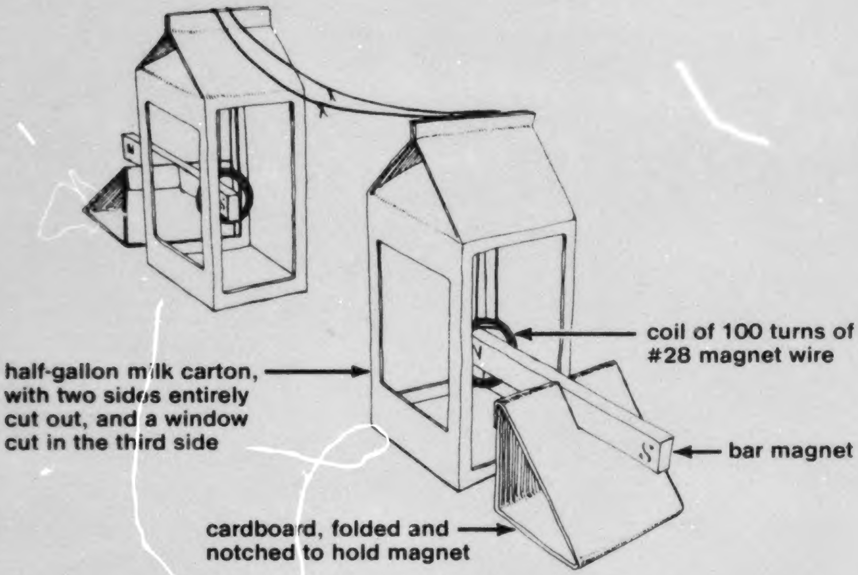
Energize the coil with a 1-1/2 volt battery. Hold the coil in one hand and a permanent magnet in the other. Can you feel any force of attraction or repulsion? Does it go away when the battery is disconnected?

Or, fit the coil into a white card, perpendicular to the coil. Sprinkle with iron filings.

The Mysterious Swing

Construct the swing set from the materials listed below. Then do the activities.

Materials and Construction


coil of 100 turns of #28 magnet wire
half-gallon milk carton, with two sides entirely cut out, and a window cut in the third side
bar magnet
cardboard, folded and notched to hold magnet
N
S

Assembly of Materials

Arrange the apparatus according to the above diagram.

1. Cut two sides of the two empty 1/2-gallon milk cartons. Cut a window in one or both of the remaining sides.

2. Make two coils by wrapping about 100 turns of wire around the end of a flashlight or other cylinder about 4 cm in diameter. Do not change direction while wrapping. Leave two tail ends of wire, each about 50 cm long, and tape the coil together in a few spots.

3. Force the two wires up through the top of the milk carton so the coil hangs as a swing about two inches from the floor of the carton. Bend the wires over slightly when the swing is in position and staple the top of the milk carton together. When you are finished the two milk cartons should look alike.

4. Strip the insulation off the ends of the wires. Twist together as shown in the diagram.

5. Fold each of the two pieces of cardboard into a triangle and cut a notch to support the bar magnet.

6. Position the bar magnets so that the north pole is centered through one coil and the south pole is centered through the other coil (see diagram).

Observations

1. What happens to the two coils when you give one coil a push?
2. What happens if you reverse the connections between the coils?
3. What happens if you reverse the poles of one of the bar magnets?
4. Trace the flow of energy through the apparatus.

Electrical Experiments Data

Resistance of Magnet Wire

This table can be used to estimate the resistance of a coil of wire. By ignoring inductance, we can use the resistance to make a rough estimate of how many amperes student motors, electromagnets, etc will draw.

Example: Estimate how much current will be drawn by 100 turns of #28 wire around a tube 5 cm in diameter, when it is connected across a 6-volt battery. ANS: The wire will be 1570 cm long (100 turns x pi x 5 cm). 1570 cm will have a resistance of 0.33 ohm (1.57 meters divided by, from the table, 4.7 meters per ohm =). With a 6-volt battery, the coil will draw (I = E/R) 6/.33 = 18 amps.

Wire gauge	Meters per pound	Meters/ohm @ 20°C
10	9.70	305.1
12	15.42	191.9
14	24.52	120.7
16	38.98	75.9
18	62.00	47.7
20	98.57	30.0
22	156.73	18.9
24	249.23	11.9
26	396.24	7.5
28	630.02	4.7

The Electric Motor

Objectives

This lesson contributes to the students' understanding of the following concepts:

The electric motor converts electrical energy into energy of motion.

The motion in an electric motor is produced by the repulsion of like magnetic poles and the attraction of unlike magnetic poles.

Format of the Lesson

Demonstration of magnetic attraction and repulsion

Demonstration of electromagnet

Discussion of commutation

Construction of electric motor

Demonstration of electric motor

Discussion of energy conversion

Materials Needed

magnets bar magnets about 150 mm long, with marked poles. Those made of Alnico provide a stronger field than those of chrome steel, though they are also more expensive: about $7 a pair. A pair will be needed for each motor you construct.

iron filings about $2.20 a pound from most science supply sources. They can sometimes be collected free from machine shops but, if you do so, degrease them before use.

overhead projector

sheet of acetate

wire copper magnet wire, 18 or 20 gauge. About 10 meters per motor; 105 meters of #20 wire (one pound) is about $6.30.

string

support such as a ring stand, from which one magnet can be suspended. (See drawing on next page.)

16-penny nails one per motor.

vinyl electrical tape

small nails

corrugated cardboard two pieces about 8 x 25 cm for each motor. These are identical to the pieces used in **The Mysterious Swing.**

medicine droppers one for each motor.

aluminum sheet from throw-away aluminum pie pans, TV dinner trays, and so forth.

wooden board approximately 3 cm by 10 cm by 25 cm.

dry cells or other source of electricity.

modeling clay one stick per motor.

electromagnet such as 100 turns of magnet wire on a 16-d nail.

compass at least one.

Teacher Background

It has been estimated that about 60% of all the electricity consumed in the United States is used to run electric motors. Thus they are a very important part of the energy situation.

Building electric motors has long been a popular activity in the science classroom. Dozens of good designs exist and can be easily located in a good library. Building a variety of designs in a class is valuable, as searching for the common elements in the different designs helps students understand the principles on which motors operate. Here, space limits us to presenting only one design.

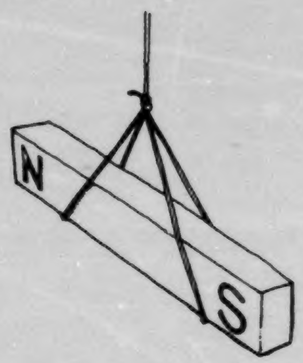
Almost all electric motors have three principal parts:

- an armature, which is a magnet attached to a shaft that can rotate
- a field magnet, which produces a magnetic field around the armature's magnetic field
- a commutator, a switch that changes the direction of the electric current flowing through the electromagnet, usually the armature

In the motor described here, the armature is an electromagnet and the field magnets are permanent bar magnets.

Magnets: Unlike Poles Attract, Like Poles Repel

Demonstrate the laws of magnetism by suspending a bar magnet. (Form two loops of string to make a harness, as shown in the drawing.)



Approach the suspended magnet with another bar magnet. The attraction between unlike poles and the repulsion of like poles will be clear. If enough magnets are available, let the students try this themselves. Most, of course, will have had earlier experiences with magnets.

The magnetic field around magnets can be demonstrated visually by using iron filings, magnets, and an acetate or clear plastic sheet on an overhead projector. Place a bar magnet on the center of the overhead projector. Lay a piece of 8½" x 11" acetate or clear plastic over the magnet. Sprinkle iron filings over the acetate and gently tap the top of the overhead projector. The iron filings will line up in the magnetic field of the magnet.

The same procedure can be used to show how like poles repel each other. Place two magnets on the overhead projector with like poles about an inch apart. Then show the magnetic field around two unlike poles in the same way.

Demonstration of Electromagnet

Take a small electromagnet (some turns of wire around a nail) and see if it attracts and repels the suspended bar magnet. Mark the north and south poles of the electromagnet. If you wish, demonstrate its field on the overhead projector. Help the students see that the effects produced by the electromagnet are indistinguishable from those produced by the permanent magnet.

Now, reverse the connections to the electromagnet. Connect the wire that was connected to the + terminal of the battery to the − terminal, and vice versa. In what direction is the current now flowing? Has this changed the electromagnet? Try it on the suspended magnet, asking students to describe what has happened. (ANS: The poles of the electromagnet have changed places.)

Commutation

Tell the students that a very useful form of mechanical energy is rotation of a shaft, like the axle of a cart. Can we change the push and pull of magnets into rotation of a shaft?

Ask how we could make the suspended bar magnet turn. At a student's suggestion, bring two hand-held bar magnets near it, on opposite sides and at 90 degrees to the suspended magnet's position. The suspended magnet will turn, then stop. Ask the class why it stopped. (ANS: It stopped once unlike poles were as near as possible to each other. Their attraction prevents further rotation.)

Ask the class what would have happened if, when the suspended magnet swung so that it just reached the stationary magnets, the poles of the suspended magnet had suddenly changed, so that south became north and north south. You may wish to diagram what you mean on the chalkboard. (ANS: Instead of attracting each other, the magnets would have started to repel each other at that point, so the suspended magnet would have kept moving.)

Is there any kind of magnet whose polarity we can suddenly change? (ANS: An electromagnet, by changing the direction of the current.)

That is how most electrical motors work. Define for the class the words *armature*, represented by the spinning magnet; *field magnets*, represented by the hand-held magnets; and *commutator*, the switch needed to change the polarity of the electromagnet.

If you are presenting the motor as a teacher demonstration, connect it and demonstrate its operation.

If you intend to build motors as a class activity, divide the class into groups, pass out the activity sheet and the materials, and proceed with construction. You will probably run over the period and have to resume in the next class meeting, so give some thought to where the projects can be stored.

After the Activity

When the majority of motors are running, discuss the following questions:

1. For electricity to flow through a circuit, a complete circular path must be provided. Trace the path in the motor.
2. How many different energy conversions can you find in our setups? Write them on the board.
3. After the motor has been running for some time, stop it and feel the armature. What do you detect?

Detecting Electricity: Electric Meters

Ask if we can see electricity? Can we smell it? Feel it? (ANS: Not if it's low voltage; try one of the dry cells and see.) Electricity is a form of energy that we often need an instrument to detect.

Ask students how many have seen the kind of panel meters that use a moving needle to tell us something about an electric current. Such meters are often found on stereos, for example. These meters work on the same principle as an electric motor. We can build a meter something like those in the stereo out of a compass, by wrapping a coil of wire around it. If the compass is then positioned so that the compass needle is parallel to the coil, the compass needle will be deflected when a current passes through the coil.

Make one or more of these. Disconnect the batteries from the electric motors the students have made and connect the compass with the coil of wire around it. Give the armature of the motor a spin. What happens? Why?

(There are several other ways students can detect a current, perhaps less expensive than compasses. One of the simplest is a flashlight bulb in a porcelain socket (about 60¢). The most suitable bulb is a type 131, if you can find it, because it is designed to operate on 1.3 volts and draws only one-tenth of an ampere. A light emitting diode can also be used with a series resistor to limit current.)

Projects for Independent Investigation

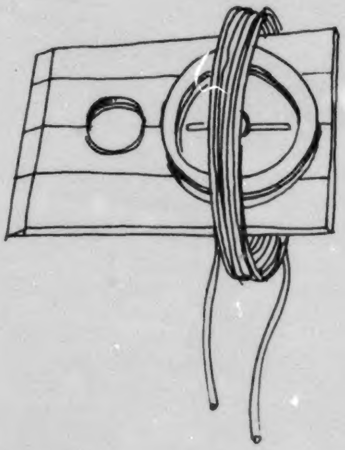
1. Build another electric motor with a different design.
2. Suppose instead of putting electricity into your motor you put motion into it. Predict what will happen. Invent a way of testing to find out if your prediction is correct.
3. Bring in some commercial electric motors, preferably burnt out. Take them apart and identify the different parts and their functions.

Additional Resources

Boy and a Motor, by Raymond F. Yates. (NY: Harper-Row, 1944.)

Energy, by Mitchell Wilson. (NY: Time-Life Books, 1968.) Directions for a motor will be found on pp. 132-135.

How to Make and Use Electric Motors, by Al G. Renner (new ed., Putnam, 1974).



Making an Electric Motor

In this activity you will build an electric motor. To do so, you will need the following parts:

One medicine dropper

Modeling clay (one stick)

Two bar magnets

Three 16-penny nails

Four small nails

Insulated bell wire or magnet wire (18 or 20 gauge)

Electrical tape

Two pieces of corrugated cardboard

Aluminum sheet

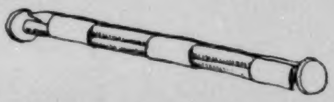
Board approxmiately 2 cm by 10 cm by 25 cm

Dry cells, one 6-volt lantern cell or four 1½-volt #6 dry cells

Do you have everything you need?

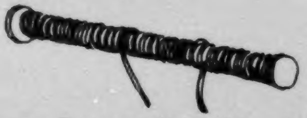
Procedure

Step One: Place two 16-penny nails next to each other as shown. Tape them together.

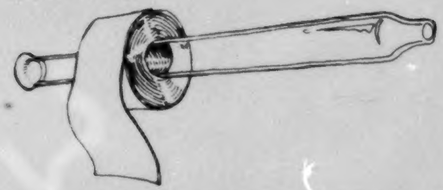


Step Two: Make an electromagnet by winding wire around the nails to form the armature. Start winding at the center of the armature. Wind out to the end of the nail and then wind back to the center. Continue on out to the other end and then back to the center. Be careful never to change the direction you are wrapping. This electromagnet will be your armature.

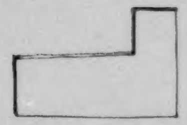
Leave 10 cm of wire extending from each end of the coil.



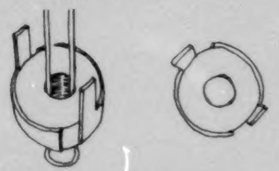
Step Three: Remove the rubber bulb from a glass medicine dropper. Wrap electrical tape around a spot about 1 cm from the end of the glass tube until it is about 1 cm in diameter.



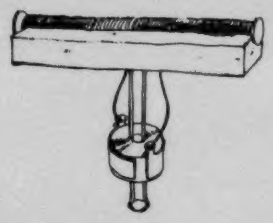
Step Four: Cut two pieces of thin aluminum sheet into L-shapes of the size shown in the drawing. Form them around the taped cylinder and trim so there is a narrow gap between the two strips. The two strips must not touch!



Fasten the L's to the cylinder with narrow strips of electrical tape around the top and the bottom.

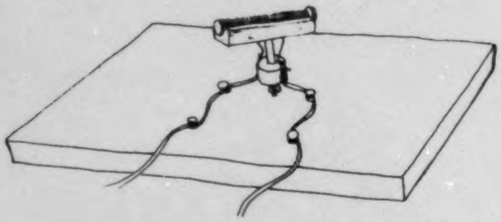


Step Five: Push the medicine dropper vertically into the middle of a stick of modeling clay. (The heavy clay acts as a flywheel.) Push the electromagnet you have wound into the top of the stick. Fasten the leads from the armature to the two pieces of aluminum. They are now your *commutator*.

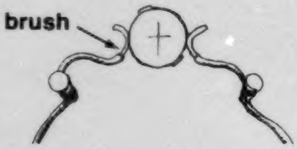


Step Six: Drive a 16-penny nail through the center of the board. Place the medicine dropper over the nail.

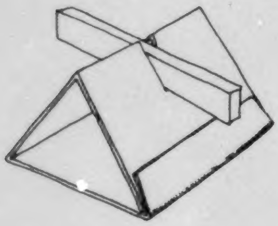
Step Seven: Drive the four small nails into the wood base as shown.



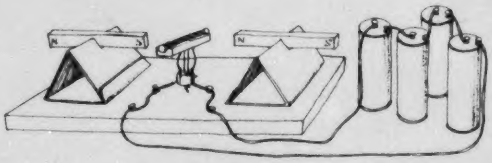
Take two 15-cm sections of wire and remove about 1 cm of insulation from the ends of each section. Fasten them around the nails so that they rub up against the commutator on opposite sides.



Step Eight: Fold each of the cardboard pieces into a triangle. This will be a support for the bar magnets. Tape the ends together. Cut a slit to hold a bar magnet.



Complete Motor Assembly



Assemble the apparatus as shown above.

1. To get the motor started it may be necessary to start the armature spinning by hand.

2. Adjustments may need to be made between the brushes and the commutator.

3. The field magnet supports should be thumbtacked down to the wood base after the distance between the field magnet poles and the armature has been adjusted.

Observations

1. What form of energy is present in the spinning armature?
2. List five forms of energy present in the moving electric motor assembly

______________, ________________,

______________, ________________,

______________.

3. After the motor has been running for a short time, stop it and feel the coils of the armature. What do you detect?

______________.

4. Name some ways the energy in the spinning armature of an electric motor can be put to practical use.

Electric Motor Inventory

Use the worksheet below to take inventory of the electric motors in use in your home. For each one you check, also write down how you might do the same job without the use of an electric motor.

Appliances with Electric Motors	Other Ways of Doing the Job
☐ garbage disposal	
☐ mixer	
☐ blender	
☐ ice cream maker	
☐ fan	
☐ record player	
☐ tape player	
☐ garage door opener	
☐ electric drill	
☐ electric saw	
☐ hair dryer	
☐ refrigerator	
☐ air conditioner	
☐ furnace (blower, oil pump)	
☐ toothbrush	
☐ clock	
☐ sewing machine	
☐ any others you can think of	

Notes

Changing Heat and Light to Electricity

Objectives

This lesson contributes to students' understanding of the following ideas:

A photovoltaic cell (solar cell) converts light energy to electrical energy.

A thermocouple converts heat to electrical energy.

Energy can be converted from one form to another, but it cannot be made or destroyed.

Format of the Lesson

Review of previous lesson (light bulb)

Thermocouple experiment

Solar cell demonstration

Thought experiment

Materials Needed

For the thermocouple:

galvanometer such as a compass with 30 turns of magnet wire wrapped around it.

copper wire such as bare #16 solid copper.

iron wire available on spools in some hardware stores, or unbraid picture hanging wire with the coarsest strands you can find, or use iron coat hanger wire. Don't use galvanized wire.

candle or other heat source.

ice cubes and containers or any other way of chilling some wires (for teacher version only).

pliers and cutters for working with the wire.

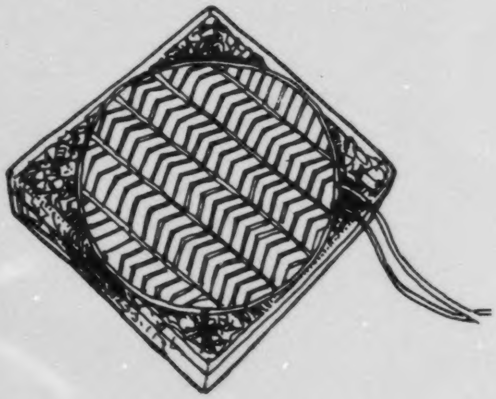
1-quart plastic container as support for student version.

sandpaper

satellite pictures

For the solar cell:

Solar cell. A three-inch diameter, good quality cell can be purchased for about $10. These cells are delicate slices of silicon crystal. To prevent breakage, we suggest you put them in clear plastic boxes with a piece of foam underneath to hold them against the side of the box. The wires can be let out through a notch filed in the box lid. Note that if cells are broken, they will still work; the only difficulty is soldering new leads to them.



Radio Shack	3" #276-123	$ 8.99
	2 × 4 cm #276-120	2.99
Edmund Scientific	3" #42, 270	19.95
	1 × 1 cm #30817	2.95
Herbach & Rademan	3" #TM21K748	8.50
	2 × 1 cm #TM20K807	six for 5.40
Meshna	3" #SP297A	8.50
	2 × 2 cm #H-12	1.50

motor that can be run on a solar cell. Available from:

Radio Shack (Catalog #273-213	three for 1.98)
Edmund Scientific (Catalog #30807	2.95)
Herbach and Rademan (Catalog #TM21K896	1.95)
Meshna (#SP-350, motor and propeller; SP-288-SP288A	1.75)

Teacher Background

Thermocouple

When two dissimiliar conductors are joined in a circle and the temperatures of the two junctions differ, an electrical current will flow around the circle. This is called the Seebeck Effect; an explanation can be found in an adult encyclopedia or physics text.

Our purpose is not to explain the Seebeck Effect or even tell students its name, but to use this phenomenon as another way of focusing students' attention on energy flows and the first law of thermodynamics.

We will make our thermoelectric generator from wires made of two different metals. Because iron and copper wires are readily available, we will use those two metals. If you can find special alloys like constantan, they will produce larger currents. The current can also be increased by increasing the temperature difference between the junctions, and by increasing the number of junctions.

This lesson plan describes two thermocouples. One, which we suggest is more appropriate as a teacher demonstration, requires ice. It has the advantage of visually emphasizing that we are making use of a heat flow, from hot to cold, but getting ice can be a hassle. Version two does not require ice, and uses a larger number of junctions. It is therefore more properly called a thermopile.

The chief practical use of thermocouples is not as a source of electrical power but as a means of measuring temperatures. Thermocouples are regularly used to measure temperatures in furnaces full of molten steel, as well as the heat of stars (through a telescope, of course).

Solar Cell

Again, there seems little point in trying to explain to the class how a photovoltaic cell works. Some students might be encouraged to pursue this subject independently; some excellent resources are available.

Solar cells as a power source are dealt with in Unit Five.

Review the Previous Lesson

Ask students to describe how they made a light bulb. Then ask them to describe what happened in terms of a flow of energy. What kind of energy did we start with? What kind did we get?

Review assignment: what other ways of changing electricity to light have the students found besides the incandescent lamp? You may wish to have some students make a display on this topic.

Tell the students that we will now try to do the conversion backwards: instead of changing electricity to light and heat, we will try to change heat and light to electricity.

Thermopile Experiment

Decide whether to use the thermocouple as a student experiment or as a demonstration by you. The student experiment version is described on the accompanying worksheet, and can be built by groups.

Divide the class into groups.

Pass out the worksheet.

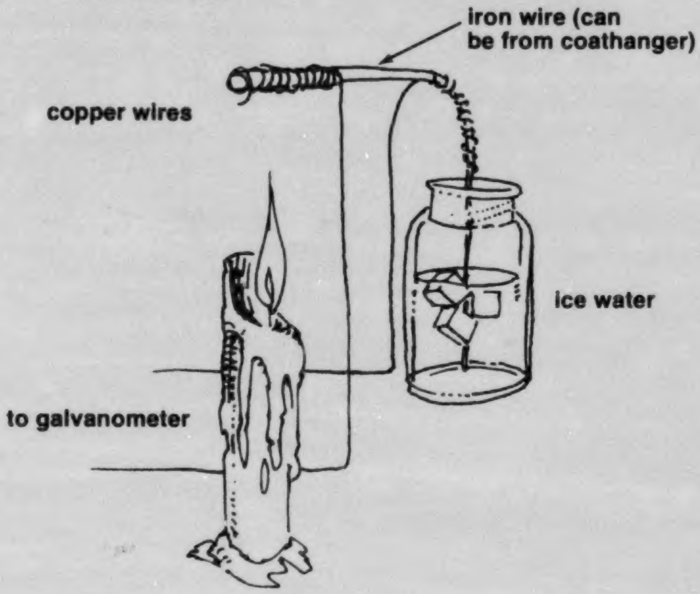
Pass out the materials.

Demonstrate how to twist wire together to get the best joint. We can involve more of the wires' surfaces in the junction if we don't just wrap one wire around another. Ideally, we want them to spiral together. This is easier to do if the wires are about the same size. Show the students this trick: lay one wire over the other at right angles. Hold them with your thumb. Grab the ends of the wires with the pliers. Turn the pliers, putting a twist in the wires and letting this twist slowly draw more wire into the joint. Finish by crimping together the short ends you've been holding in the pliers. You may want to practice this yourself in advance. It is not essential that the joints be done this way, but it helps.

Sandpaper may be needed to clean any corrosion or enamel insulation from the parts of the wire that are to be joined.

We suggest that, rather than giving the students matches, you ask the students to call you over to light the candle when they are ready. This will give you a chance for a quick inspection of the students' apparatus before they test it.

If you choose to do the demonstration model, refer to the drawing below for the details of its construction.



Questions for Discussion

1. What happened when we heated every other junction?

2. What would happen if we heated every junction (or both junctions)? Try it.

3. What do you think would happen if we heated the junction we were cooling and cooled the one we were heating? (Much easier to do on the teacher version.) After eliciting guesses, try the experiment.

4. Is electricity flowing in our experiment? What is its path?

5. Is heat flowing in our experiment? What is its path?

Collect and put out of sight all the thermocouple materials.

Solar Cell Demonstration

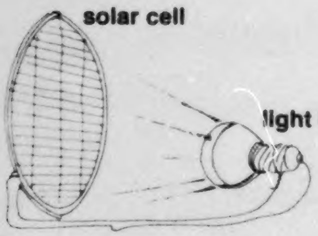
Show the students photographs of space satellites (e.g., from NASA—U.S. Government Printing Office 1973-779-978/04). Point out the solar cells and ask students if they can tell what these are.

Produce your solar cell and give students a good look. Connect it to the motor, shine a light on the cell, and observe the motor running. (You may need to tape a piece of paper to the motor shaft.) When the cell is shaded, the motor stops. If you have an overhead projector, this can be done for the class on the stage of the projector. But at some time give all the students a chance to play with the motor and cell.

Ask students to summarize the energy conversion that is taking place: light energy to electrical energy.

A Thought Experiment

Ask the students to imagine that we have a machine made of a light bulb and a solar cell. Draw this machine on the chalkboard.



All the light from the light bulb shines on the solar cell, which makes electricity that goes into the light bulb, which lights the light bulb, and the light shines on the solar cell, which...and so on. Will this machine work? Will the light bulb keep shining? If not, why not? (ANS: Some of the electricity is converted to heat, not light. The solar cell probably doesn't convert all the light to electricity. Some of the electricity is lost in heating the wires between the cell and the bulb.)

Homework Assignment

1. Look up perpetual motion machines in the encyclopedia. Pick one and describe to the class how it was supposed to work. See if they can tell why it wouldn't work.

2. Find another way heat could be changed to electricity.

Projects for Independent Investigation

1. In the Soviet Union, you can buy a thermoelectric generator like the one you made, which fits in a kerosene lantern and runs a radio in places where there's no electricity. Could you make a radio run on thermoelectrically generated electricity from a lantern?

2. If students have access to a voltmeter and ammeter, they can do a quantitative investigation of the thermocouple and thermopile. Perhaps using graphs to display their results, they might investigate questions like:

How does adding more junctions affect the voltage produced?

What happens if the additional junctions are wired in parallel instead of in series? (You may need to explain the differences between parallel and series.)

Is the current produced related to the absolute temperature of the hot junction, or to the difference in the temperatures of the two junctions?

As the temperature difference increases, how does voltage and current (power) increase? Graph it. Is it a straight line? A curve? (Hint: High temperatures, such as can be reached by using a Bunsen burner, can be estimated by the color of the incandescence.

Colors of Heated Steel in Diffused Daylight

Colors	°C
Dark blood red, black red	532
Dark red, blood red, or low red	566
Dark cherry red	635
Medium cherry red	677
Cherry, full red	746
Light cherry, bright cherry	843
Salmon, orange	899
Light salmon, light orange	940
Yellow	996
Light yellow	1080
White	1204

3. Try different colored filters over the solar cell and see if some colors are converted more efficiently than others.

4. Bell Laboratories has created an excellent kit for building solar cells, available from Edmund Scientific (Catalog #71, 906, $36.50) or Herbach and Rademan (Catalog #C10-02, $19.95). The activities are difficult (such as diffusing ions into the surface of the silicon) and should only be attempted by the dedicated. Not suitable for the elementary grades or the average junior high student.

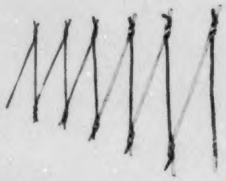
Building a Thermopile

To do this experiment you will need the following materials:

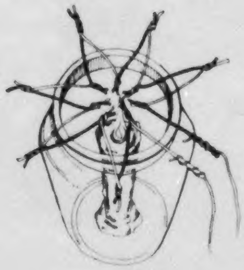
- ☐ copper wire
- ☐ iron wire
- ☐ candle
- ☐ quart plastic container
- ☐ modelling clay
- ☐ galvanometer
- ☐ pliers

Do you have all the things you need?

1. Cut twelve pieces of copper wire 10 cm long.
2. Cut twelve pieces of iron wire 7.5 cm long.
3. Using pliers, twist the wire together to make a chain like this of alternating copper and iron wires:



4. Put the candle in the bottom of the container. (You may need some modelling clay to get it to stand up.)
5. Arrange the wires in a crown pattern, like this.



6. Put the wires on the plastic stand.
7. Connect the galvanometer to the two copper wires.
8. Ask your teacher to light the candle.
9. On a separate sheet of paper, describe what happened.

Changing Light to Motion

Objectives

This lesson contributes to students' understanding of the following concepts:

Light heats objects which absorb it.

Light energy can be converted to motion.

Some light is not visible.

Heat is not a form of light.

Format of the Lesson

Introduction of radiometer

The more light, the faster it spins

How the radiometer works

Different forms of light

Comparison of infrared radiation with heat

Materials Needed

Crookes radiometer available from novelty stores, as well as scientific supply houses. (Edmund Scientific, Catalog #60,082, $5.95.) Providing each group with its own radiometer is helpful though expensive, since it gives individual students a chance to try the device for themselves.

source of visible and infrared light sunlight can be used for the visible light, but a more manipulable source is helpful. One can be made by using a lamp socket on the end of a cord. Some "trouble lights" are suitable, or make one by plugging a prong-to-socket adapter (.75¢) into an extension cord. A small reflector flood makes a good light. Convert it to infrared by adding a filter such as one from Edmund Scientific (Catalog #60,033), $4.95. Or use an ordinary flashlight; an infrared filter to fit a flashlight is also available from Edmund (Catalog #42,143) for $2.

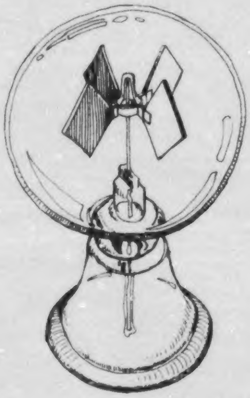
Introducing the Radiometer

Set up the radiometer in a window (or direct a visible light source on it, though the window is better since, if students are not already familiar with the radiometer, using the window avoids "giving away" the connection with light). Ask students to describe what's happening. What kind of energy can be detected inside the glass bulb? (ANS: Motion, or mechanical energy.)

Where does this energy come from? How can we tell?

Compare the intensity of the light falling on the radiometer with its rate of rotation. Vary the light by shading the radiometer or placing it varying distances from the window or light source. Quantify the energy of motion by counting the number of rotations in 30 seconds. If several radiometers are available, ask groups of students to investigate different intensities.

Ask where the energy of the turning vanes comes from. Students will answer that it must be from light, since the vanes don't turn in the absence of light, and the more light there is, the faster the vanes turn.



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How the Radiometer Works

What can be observed about the vanes? (ANS: They are black on one side; white on the other.)

Which absorbs more light, black or white? (ANS: Black.)

Which side of the vane is hotter? (ANS: The black side.)

Explain that there is air inside the radiometer (but at less than atmospheric pressure). The unequal heating of the vanes leads to a very small difference in air pressure at the surface of the vanes, which makes them rotate.

Please note that the explanation given by the manufacturer on the radiometer packaging (that molecules striking the black side bounce off with more energy, giving the vane a greater kick) is at best oversimplified and should not be used. The rotation of the radiometer is due to a phenomenon called thermal transpiration, in which gas creeps toward the hotter parts of the vane causing locally increased air pressure.

Refer students who want further information to the article "Radiometer" in the **Encyclopedia Britannica.**

Light Pressure—Optional Topic

With advanced students, you may wish to discuss the following additional information:

- If all the gas could be removed from the bulb, and the bearing had even less friction, the vanes would turn in the opposite direction!

This would occur because of "light pressure." The photons of light are more strongly absorbed by the black side than the white side. In the space in front of the white side, the photons reflected from the white side are added to those streaming in, so there is a greater "density" of photons in front of the white side than in front of the black side. The greater pressure causes the radiometer to turn. In fact, however, it is not practical to demonstrate light pressure with radiometers of this design.

The effects of light pressure can be seen in the motion of comets' tails, which swing to point away from the sun. Light pressure is also of crucial importance in what happens inside stars.

A Light We Cannot See

Provide two artificial light sources, one of visible light and the other largely infrared. You can do this by putting a filter in front of a flood lamp, or by using a commercial heat lamp. Ask the students which light is brighter; they will choose the visible light.

As our earlier investigations with the radiometer showed, we can vary light intensity by adjusting distance. If you can darken the room, shine the two sources alternately on a piece of paper, moving the visible source farther and farther away from the paper, until an approximate visual balance is reached. Note the distances.

Now compare the strengths of the two light sources by shining them on the radiometer from the distances established in the visual comparison. The infrared source will cause the faster rotation. Why?

Point out that we cannot see all kinds of light. Visible light is only one part of the spectrum of radiation. All incandescent light bulbs emit a mixture of visible radiation and infrared radiation, but one of the bulbs we are using has been made to emit mostly infrared and little visible light. The radiometer is sensitive only to how much heat is produced by the absorption of the light, not to whether it is blue, red, yellow, or infrared light.

As it happens, infrared light is very strongly absorbed by objects, more so than visible light. We use infrared to heat everything from rooms to freshly painted automobiles. Sometimes it is called "radiant heat." But notice that it is really radiation, not heat. Only matter can have heat; infrared radiation can and does travel through a vacuum, just like the other radiation from the sun.

Projects for Independent Investigation

1. Some students may be interested in building other machines that convert light to motion as Crookes' radiometer does, using heat as an intermediary form.

NASA designed a solar motor that consists of a long metal tube painted black and pivoted on the ends. Sunlight can only hit one side at a time, so the lit side expands more than the shaded side, warping the tube. The warped tube is unbalanced; the bulge falls — bringing the cool side up. Now it expands, the bottom shrinks, and so on.

Clear directions for building such a motor are given on pages 50-54 of **Exploring Solar Energy**, by Thomas H. Metos and Gary G. Bitter (New York: Julian Messner, 1978). It is a fairly complicated project.

A second type of "solar engine" uses rubber bands or plastic strips, which contract when they are heated. Directions for building such an engine are given on pages 126-128 of the February, 1980, issue of **Popular Science** ("Build a Sun Tracker and a Solar Engine with Solar Muscle"). A different design, for a rubber band engine, can be found in the "Amateur Scientist" columns of the May, 1956, and April, 1971, issues of **Scientific American**. These are not as difficult to construct as the NASA motor.

2. What would happen if a spinning radiometer was placed in an environment that was colder than the vanes? Such an environment can be created. Choose a tin can higher than the radiometer and only a little bit larger in diameter, which the radiometer will fit into. Paint the inside of the can flat black. Glue it into the middle of a larger tin can. Pack the space between the two cans with ice and salt. After the cans have cooled, get the radiometer spinning as fast as possible in a strong beam of light, then quickly place it in the can. You can observe what happens by looking down on the radiometer from above. What does happen? Why?

3. A prism will split light into its various colors. Even though you can't see it, the prism also splits out the infrared. Can you devise a way of measuring the heat energy in the various bands of light, including the infrared? (Hint and caution: not all blacks are equal.)

Notes

Changing Chemical to Electrical Energy

Note: This lesson involves the use of household bleach, which can cause spotting if spilled on clothing, and should be rinsed off any skin it contacts. If the directions below are followed, the chance of spills is minimal. However, when children who are not accustomed to performing experiments in class are first given this opportunity, their behavior tends to be rowdier than usual. For this reason it would be better not to pick this lesson for your first class experiment.

Objectives

This lesson contributes to developing the students' understanding of the following ideas:

Energy cannot be made, only converted from one form to another.

A battery changes chemical energy to electrical energy.

As a battery produces electricity, chemical changes alter the substances inside the battery.

It took energy to make the battery, and we recover some of that energy when we use it.

Electricity from batteries is much more expensive than electricity from the power company.

Format of the Lesson

Help students identify the significance of batteries in their lives.

Sharpen the focus for investigation.

Describe the work to be done, with a blackboard diagram.

Divide the students into groups of three.

Release the materials and conduct the experiment.

Collect all materials.

Discuss.

Assign homework.

Materials Needed

household bleach about one quart for ten groups of students. Sold under brand names like Clorox and Purex, this is a solution of about 5% sodium hypoclorite in water. The cheapest brand will do; 2 quarts will cost 60¢.

aluminum foil one-half a running foot per group. The narrowest width will do, and the thinner foil demonstrates the "eating up" of the foil more dramatically than the heavier gauge. Since you only need five feet or less, why not salvage it from your own kitchen?

paper towel one towel per group.

copper wire of the kind used to wire lamps and make light-duty extension cords. Ask at a hardware store for five feet of two conductor 16-gauge zipcord. This will cost about 60¢. Ask the sales clerk to cut the wire into five pieces one foot long; pull these apart to make 10 pieces of wire with only one conductor. Remove four inches of insulation on one end of the wire and one inch on the other (if you don't feel you can strip the insulation, get a janitor or parent to do it; it only takes five minutes). These wires can be saved and reused next year.

plastic containers pint size, one for each group. These should have wide mouths and broad flat bottoms, so they don't tip. The plastic containers ice cream comes in are fine.

testers one for each group, such as flashlight bulbs in miniature sockets with wires already attached. Use bulbs which are meant to run on a single cell (type 112, 123 or, preferably, 131, which draws less current). Fine wire wrapped around small compasses can also be used, but the light is much more dramatic.

plastic pail one for disposing of the bleach when the experiment is over, if you don't have running water in your classroom.

For Class Discussion Before The Experiment

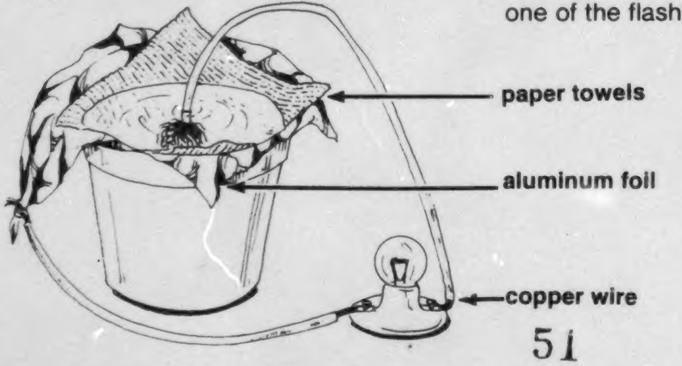
1. Do you use batteries in your home? For what?

2. What kind of energy do we get out of batteries?

3. Where do you think the energy comes from? (The point of this question at this time is only to remind students that all energy must come from someplace.)

4. How long do batteries last?

5. Is electricity from batteries more expensive than electricity from the wall plug? (Just gather a range of opinions; students will compute the answer to this question later.)



Sharpening the Focus

Tell the students something like "We're going to try to make some batteries. To see if the batteries work, we'll use our light bulbs. If the batteries make electricity, the light bulbs will light up."

Put the diagram below on the board. You may wish to introduce the words "Insulator," "Electrolyte," "Electrode."

Caution the children not to pick up their battery after you have added the bleach (electrolyte).

Ask one child from each group to come up and get their materials. While the children are performing the experiment, concentrate your energies on the **doing** of the experiment and not on **explaining** it.

Performing the Investigation

Here are the instructions to the students:

1. Line the inside of the cup with aluminum foil. It doesn't matter whether the shiny side or the dull side is up. Let a corner of the foil hang over the edge of the container.

2. Cover the aluminum foil with paper towel. The paper towel serves as an insulator.

3. Scrunch up the strands of copper at the end of the piece of zipcord that has 4 inches of wire exposed.

4. Connect the other end of the zipcord to one of the flashlight wires.

5. Connect the other flashlight wire to the aluminum foil, by pinching the foil around it.

Completing steps 4 and 5 before adding the bleach lessens the chance that students will spill bleach.

You or an aide now walk around the class, pouring enough undiluted bleach into each cup to cover the copper wire.

After a few minutes, the lights will begin to glow. If someone's doesn't, the most likely problems are:

1. Light bulb not screwed in.

2. No contact between foil and wire to bulb.

3. No contact between zipcord and wire to bulb.

In a brightly lit room, students may need to cup their hands around the bulb to see it glow.

For Class Discussion After The Experiment

1. Some energy left the light bulbs and spread throughout the room. What kind of energy was it? (ANS: Light and heat.)

2. Why did the batteries we made stop providing electricity?

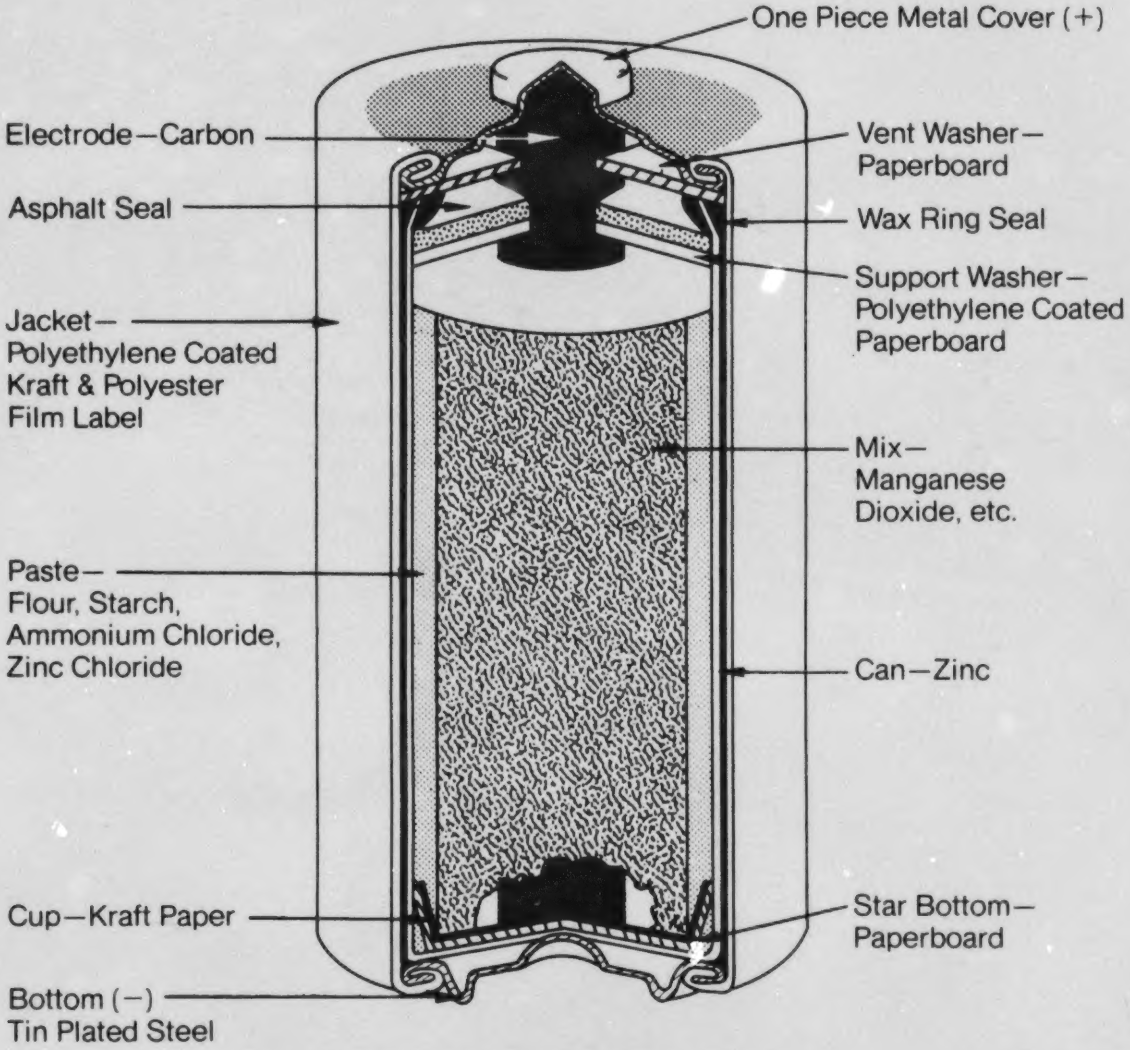
3. What happened to the aluminum?

4. What do you think we would have to do to get the aluminum back the way it was?

5. Did it take energy to "make" aluminum?

Projects for Independent Investigation

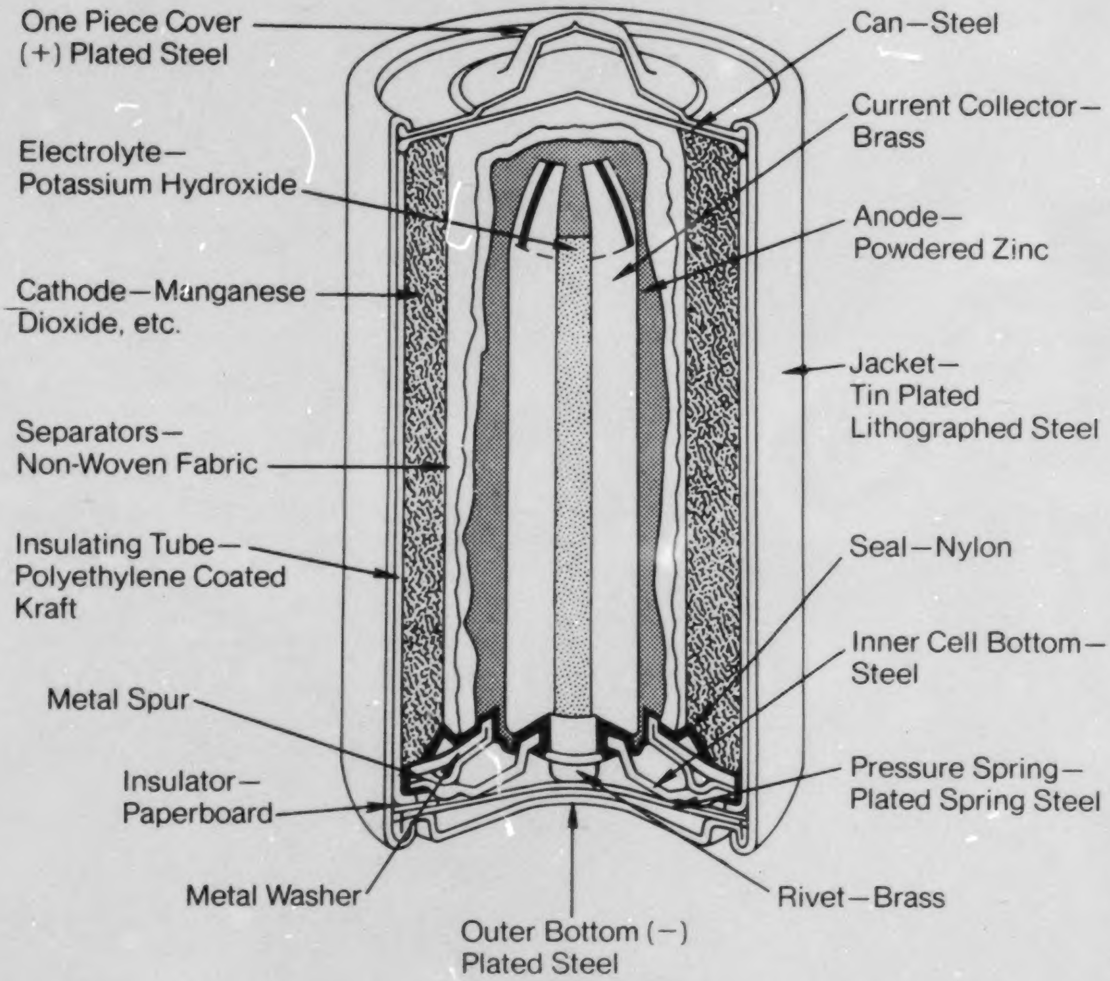
1. Build a storage battery and demonstrate it to the class. An average high school chemistry student can do this.
2. Build a fuel cell. This is a very difficult project that requires considerable perseverance and ingenuity, and would make a substantial science fair project. See "The Amateur Scientist," **Scientific American**, November, 1967.
3. Take apart two exhausted flashlight batteries, one carbon-zinc and one alkaline energizer. Share with class.
4. Investigate electric cars and report to the class on what they cost to buy, what they cost to own, and what they can do (how much can they carry, how far, and how fast)?
5. Investigate rechargeable nickel cadmium batteries for flashlights. How much do they cost, how many times can they be recharged, how does the cost of using them compare with the cost of using other kinds of batteries?
6. Find out how a car's electric system works and report to the class.


One Piece Metal Cover (+)
Electrode—Carbon
Vent Washer—Paperboard
Asphalt Seal
Wax Ring Seal
Support Washer—Polyethylene Coated Paperboard
Jacket—Polyethylene Coated Kraft & Polyester Film Label
Mix—Manganese Dioxide, etc.
Paste—Flour, Starch, Ammonium Chloride, Zinc Chloride
Can—Zinc
Cup—Kraft Paper
Star Bottom—Paperboard
Bottom (−) Tin Plated Steel

CROSS SECTION OF STANDARD ROUND CELL

53

Courtesy of Union Carbide Corporation


One Piece Cover (+) Plated Steel
Can—Steel
Current Collector—Brass
Electrolyte—Potassium Hydroxide
Anode—Powdered Zinc
Cathode—Manganese Dioxide, etc.
Jacket—Tin Plated Lithographed Steel
Separators—Non-Woven Fabric
Insulating Tube—Polyethylene Coated Kraft
Seal—Nylon
Inner Cell Bottom—Steel
Metal Spur
Insulator—Paperboard
Pressure Spring—Plated Spring Steel
Metal Washer
Rivet—Brass
Outer Bottom (−) Plated Steel

CUTAWAY OF ALKALINE CELL (PRIMARY TYPE)

Courtesy of Union Carbide Corporation

Making a Battery

In this activity you will make a battery that will provide electrical energy. To make the battery, you need:

☐ a piece of paper towel

☐ aluminum foil

☐ one piece of copper lamp cord with 10 cm of insulation stripped from one end

☐ a plastic cup

☐ a flashlight bulb in a socket with two wires attached

Do you have everything you need?

Procedure

Before beginning, read all the steps.

Step One: Line the inside of the cup with aluminum foil. At one place let a corner of the foil hang over the edge of the cup. The aluminum is one *electrode* of the battery.

Step Two: Line the aluminum foil with paper towel. The towel acts as an insulator. Don't let any of the towel hang over the edge of the cup.

Step Three: Take the copper wire. Scrunch up the strands to make a loose ball. Put the ball in the cup so that the other end of the wire hangs out of the cup. The paper towel should keep the copper wire from touching the aluminum foil at any point. The copper wire is the other *electrode* of the battery.

Step Four: Connect one wire from the flashlight bulb to the aluminum foil by twisting foil and wire together. Connect the second wire from the flashlight bulb to the copper electrode of the battery by twisting the two wires together.

Step Five: Place the cup well away from the edge of the table. Call your teacher. Your teacher will pour into the cup the *electrolyte*.

The electrolyte in this battery is a solution of sodium hypochlorite in water, which is used as household bleach. It is a very active chemical which must be treated with respect.

Do not put your fingers in the bleach.

Do not move the cup or bump it once it has been filled with bleach.

If bleach does get on clothes or skin, rinse it off with cold water immediately. It will make spots on clothing.

Your teacher will empty the cup when the activity is over.

Step Six: Observe what happens. Does the light bulb light? For how long? What changes take place in the copper wire? What changes take place in the aluminum foil? Where does the light energy the bulb is giving off come from?

Changing Electrical to Chemical Energy

Objectives

This lesson contributes to the students' understanding of the following concepts:

Energy is neither created nor destroyed.

A battery converts chemical energy to electrical energy.

Format of the Lesson

Discussion of energy flow in battery charging

Activity: electrolysis

Testing gases

Final discussion

Materials Needed

(for one group)

beaker 400-mL or similiar-sized jar

test tubes two.

insulated bell wire one meter.

power supply the activity sheet shows four 1½ volt #6 dry cells, but a 6 volt (e.g., Eveready No. 1461) or 9 volt battery (e.g., Eveready 1662) could be used. Of course, any other power supply capable of delivering 3 amps at 6 to 9 volts can also be used.

window screening copper or aluminum, not fiberglass. One running foot is plenty. Copper screening is about $2 a foot at hardware stores.

vinyl electrical tape one roll. About 70¢ a roll.

splints a dozen or so.

Preliminary Discussion

Review the flow of energy in the battery, using the chalkboard.

chemical energy → electrical energy

Note that many batteries, like the batteries in cars, are rechargeable. What is the energy flow then? (ANS: Electrical energy → chemical energy → electrical energy.)

Of course, we cannot see the chemical energy being stored inside the car battery. However, today we'll do an investigation to try to observe a conversion of electrical energy to chemical energy.

Background for the Teacher

This activity is called the electrolysis of water. ("Electro" for electricity, and "lysis" meaning breaking down; compare "pyrolysis" of wood.) Salt is added to the water to increase its conductivity. When the circuit is completed and electricity can flow in a circle through the apparatus, oxygen will be generated at the positively charged metal (the anode) and hydrogen at the negatively charged metal (the cathode). Electrical energy is breaking down the water molecules into the elements from which it is made.

The formula below shows what happens during electrolysis.

$$2H_2O + \text{electricity} \longrightarrow 2H^2\uparrow + O^2\uparrow$$

(The symbol "↑" means the product is a gas.)

When we burn the hydrogen, the formula is reversed.

$$2H_2 + O_2 \longrightarrow 2H_2O + \text{electricity.}$$

Setting Up the Activity

In most classes, the availability of batteries or a power supply will decide whether this must be done as a demonstration or can be done by groups of students. Even if the activity is done as a demonstration, consider distributing the handout to help students follow the investigation.

If students are working in groups, be sure the circuit is disconnected when at most 5 cm of hydrogen is visible. Also, a small quantity of hydrogen may be generated inside the window screen. It will dissipate harmlessly.

Be sure there are no open flames near the apparatus.

Testing the Gases

When all groups have generated a visible quantity of gas, ask the class what they think has happened. What are the two gases? How could we find out?

Offer to perform one test yourself: the glowing splint test. This test should be done by a responsible adult.

When a glowing splint is put into the oxygen, the glow will brighten.

When a glowing splint is put into the hydrogen, a loud pop will be heard. This is due to the rapid combustion of the hydrogen and shows that it burns and could be a fuel. Can you see the water droplets?

Questions for Discussion After the Activity

1. We made a fuel out of ordinary water. Is this free energy?
2. What energy did we start with? What energy did we end up with?

Homework

Ask students to complete written answers to the questions as homework.

Fuel from Water

In this activity, we will try to make a fuel out of ordinary water! To do the investigation, you will need:

☐ *a 400-mL beaker or jar*

☐ *two test tubes*

☐ *insulated bell wire* (about one meter)

☐ *4 dry cells* 1½ volts each or similar power source

☐ *salt* (1 teaspoon)

☐ *two pieces of metal window screen*

☐ *electrical tape*

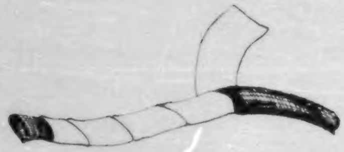
Do you have everything you need?

Procedure

Step One: Fill the container about ¾ full of water.

Step Two: Fill the two test tubes full of water and invert them into the container. There shouldn't be any air in the test tubes after they are inverted. If there is, try again.

Step Three: Cut two pieces of window screen about 1 cm wide by 18 cm long. Wrap each section with electrical tape.



Step Four: Bend the screen to fit up into the test tubes and down over the edge of the container, as the diagram indicates. Insert the screening in the jar.

Step Five: Cut the bell wire into the pieces shown in the diagram. Assemble the circuit, following the diagram. To connect the wire to the screen of the electrodes, thread it through the holes in the screen. Leave one wire between dry cells unconnected.

Step Six: Put a teaspoon of salt into the water and stir.

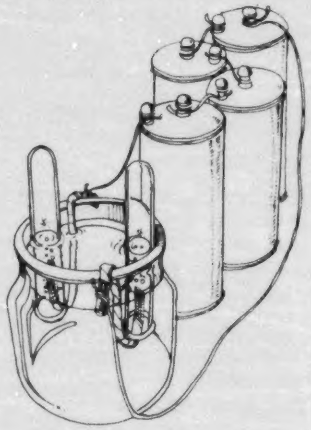
Step Seven: Connect the last wire and observe.

Step Eight: The apparatus may have to run for some time before enough gas collects in the test tubes. When 5 cm of gas has collected in the tube with the most gas, disconnect one of the wires. Leave the tube inverted in the water, and wait for instructions from your teacher.

Observations

Answer these questions on a separate sheet of paper.

1. Notice that one of the tubes is connected to the positive terminal of the battery (the screw marked +) and the other to the negative terminal (the screw *marked* −). Which tube collected the greater volume of gas?
2. Measure the height of the gas in the two test tubes with a ruler. The volume of gas in one tube is how many times greater than the volume in the other tube?
3. Do you know the chemical formula for water? What is it? What chemical elements is water made of?
4. Describe what happened when your teacher put a glowing splint in each of the tubes.
5. What do you think the gases that collected in the tube were?
6. Where did the energy that made the "pop" come from?



The Concept of Heat

Physicists have a narrower, more precise meaning for the word "heat" than we do in ordinary speech, just as they do for the word "work." In the science classroom we should use the physicists' definition, because it makes possible a clearer, more consistent description of the facts. (Using the common-sensical notion of heat leads to confusion when students try to think about how energy behaves, and will create a definite "unlearning" problem for students who go on in science.)

Energy being transferred between two bodies solely because of a difference in their temperatures is called heat. Thus heat is a form of "energy in transit," since it is energy flowing from one body to another. (All other energy in transit is work.)

Because heat is a form of energy in transit, to a physicist it makes no sense to talk of "the heat stored in a body." As Mark Zemansky explains in **Heat and Thermodynamics** (5th edition, NY: McGraw-Hill, 1968):

"Heat is energy in transit. It flows from one part of a system to another, or from one system to another, by virtue of only a temperature difference. When this flow has ceased, there is no longer any occasion to use the word 'heat.' It would be just as incorrect to refer to the 'heat in a body' as it would be to speak of the 'work in a body.' The performance of work and the flow of heat are methods whereby the internal energy of a system is changed. It is impossible to separate or divide the internal energy into a mechanical and a thermal part."

Zemansky goes on to quote from Slater's **Introduction to Chemical Physics.** Slater says:

"It would be pleasant to be able to say, in a given state of the system, that the system has so and so much heat energy. Starting from the absolute zero of temperature, where we could say that the heat energy was zero, we could heat the body up to the state we were interested in, find [the quantity of heat transferred] from absolute zero up to this state, and call that the heat energy. But the stubborn fact remains that we should get different answers if we heated it up in different ways. . . . There is nothing to do about it."

The idea that heat is something that can be added to a body, stored in it, and then removed is a carry-over from the thinking behind the caloric theory of heat—which was disproved more than a century ago by Count Rumford, who was able to draw as much heat as he wanted from the cannons whose barrels he was boring. The temperature of a body can be raised by providing energy in ways other than the transfer of heat, (rubbing it, for example, or if it is a gas, compressing it), and we can transfer heat to a body without raising its temperature—for example, transferring heat to a cup of water full of melting ice cubes will not raise its temperature. The fact that something is hot does not show it is "storing heat," any more than the fact that a body is moving shows that it is "storing work."

To observe the physicist's definition, simply be careful to use the word "heat" only when you are referring to a flow. In practice, this isn't at all awkward. Leaf through the better recent elementary science texts and you will notice that they only use the word "heat" when referring to a flow. Without calling attention to the fact, they use the physicist's concept of heat. And they never refer to heat stored in a body.

Obviously a hot object does contain energy by virtue of its temperature. Its temperature indicates the possibility of transferring heat to another body at a lower temperature, and it tells us something about the average random kinetic energy of the body's molecules. The energy represented by all the random kinetic energy of the molecules in a body has been called **thermal energy**—the total energy of the random motion of the body's molecules. Sunlight that strikes a solar collector is converted to thermal energy; the kinetic energy of the fragments hurled from a fissioning atom is converted to thermal energy. You can use the term "thermal energy" when you want to refer to the "heat stored in a body," and it is an easy vocabulary word to introduce because of it is easy to see its relation to "**therm**ometer."

Many physicists, however, would even rather avoid this term, because it isn't possible to say how much of the energy in a system is thermal energy. Instead, they prefer to refer to the system's internal energy, which includes all of the energy of a system except its translational energy of motion.

Heat and Its Measurement

Objectives

This lesson contributes to the students' understanding of the following concepts:

Heat is a form of motion, the random motion of molecules.

Temperature describes how fast the molecules are moving.

To measure a quantity of heat, we must measure mass and a temperature difference.

Format of the Lesson

Discussion of difference between temperature and heat

Kinetic theory of heat

Defining the calorie

Activity measuring temperature

How do we measure heat?

Activity

Materials Needed

thermometers Celsius scale, one for every two students.

jars or Thermos® bottles, one per group, though they will circulate between groups.

candles hot plates, or laboratory burners.

worksheet one per student.

Pyrex® beakers tin cans, or other containers, one per group

microscopes, microscope slide, cover glass, and either india ink or gamboge (optional) one per group, to observe Brownian movement. Gamboge is a yellow watercolor available at art supply stores; a small tube is about $3.50 but you can probably get the tiny speck needed from the art instructor.

Discussing Temperature and Heat

What do we mean when we say it's a hot day? How do we know it's hot? (ANS: The temperature is high.)

Suppose I'm hungry and I have a pizza in the freezer. I take it out. Will its temperature be high or low? (ANS: Low.)

I put it in the oven and pretty soon the cheese is all melted and gooey and the crust is crisp and the tomato sauce is bubbling. Is its temperature high or low? (ANS: High.)

Tell me, in terms of energy, what happened between the low-temperature pizza and the high-temperature pizza. (ANS: Heat energy was added to the pizza.)

There is energy in the pizza, right? In my oven, I converted some chemical energy in natural gas to heat energy, and that raised the temperature of the pizza.

What is the difference between heat, the form of energy, and temperature?

Let's look at the hot pizza again. There's a certain amount of that energy in the pizza, right? Suppose I cut the pizza in half. How much of the energy in the uncut pizza will each half have? (ANS: Half.)

OK, suppose I cut the pizza into 16 slices. How much of the energy in the original hot pizza will be in each slice? (ANS: One-sixteenth.)

What about the temperature of the slices of pizza? Will they be one-sixteenth the temperature of the hot pizza? (ANS: No, they'll be the same temperature, cooling aside.)

Here's a trick question. I have two full bottles of warm water, a bottle that holds a liter and another bottle that holds a half liter. The water is the same temperature in both bottles. In which bottle is there more energy — or are they both the same? (ANS: More energy in the big bottle.)

Kinetic Theory of Heat

Thermal energy is really a kind of motion energy, but it's the random motion of molecules. When you walk down the street, all your molecules are moving in more or less the same direction. That's what we usually think of as motion. When you get sick and you're lying in bed with a temperature of a hundred and one, your molecules are jiggling around a little faster than they would be if your temperature were ninety-eight point six. Your molecules are moving, just as they always are, but you're not moving. It's every molecule for itself, moving willy-nilly every which way. In a solid (and liquid) body like you, the molecules are more or less held in one place by other molecules.

Temperature is a description of the speed with which the molecules are jiggling. The higher the temperature of an object, the faster its molecules are jiggling.

But to measure the amount of heat energy flowing into or out or something, we need to know not only the average speed of the molecules, but also their mass. The greater the mass in motion, the more energy. Doesn't it make sense that there's more energy in a big semi-trailer traveling fifty-five miles an hour than in a motorbike doing fifty-five, even though they're both moving at the same speed.

Brownian Movement

If you have the necessary microscopes, a visual demonstration of the kinetic nature of heat makes a lasting impression on students. Put a tiny speck of india ink or gamboge into a drop of water on a slide, cover with a cover glass and view under high power. The particles of ink or gamboge dance because they are so small that there are not enough collisions with moving water molecules to average out to no motion. It is like subtracting heads from tails when flipping coins. If you flip millions of coins, the sum will be very near zero. If you flip only two, it may be +2 or −2. It is the plus and minus two's we see in the dance of the small particles.

Defining the Calorie

To measure anything, you first have to define a unit of measurement. The unit we will use to measure heat is called the calorie. Our definition will have to include two things:

1) the mass which is heated

2) the average speed of the molecules in the mass or, in other words, the temperture

The calorie belongs to the metric system,* so the units used are metric. Mass is measured in grams, and temperature is measured using the Celsius scale.

We have heat only when there is something that is being heated. It turns out. that some substances are harder to heat than others; that is, adding a given amount of heat doesn't produce the same rise of temperature in all substances. For example, if I put some cooking oil in one pot and some water in another, identical pot, and put them on identical burners on the same stove, the temperature of the oil would go up faster than the temperature of the water. It is harder to raise the temperature of water than just about anything else. Also, water is one of the commonest substances, and we do a lot of water heating in cooking, industry, and so forth. So we'll use water for our definition.

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*Actually, the calorie is not the unit of energy in the International System of Units; the joule is. Unfortunately for pedagogic purposes, there is no convenient way middle school students can measure heat in joules directly. Calories can be measured simply, so we use them.

Here is the definition of a calorie: the amount of (heat) energy needed to raise the temperature of one gram of water one degree Celsius (at 15°C).

We specify the 15° Celsius because the amount of heat needed to raise the temperature of one gram of water from 15° to 16° is not exactly the same as the amount needed to raise it from, say, 80° to 81°. However, the difference is so small we'll ignore it in our own investigations, because we can't measure that precisely anyway.

We're going to do an activity to measure heat, but first let's practice measuring temperature.

Divide the class into groups and distribute the thermometers.

Confirming Students' Skill in Thermometer Reading

The initial activity provides an opportunity for you to satisfy yourself that all students understand how to read a thermometer. Since most students are able to do this, working in pairs can provide those who do not have the skill with a tutor.

Ask the students to number a sheet from one to however many groups you will have. In advance, prepare that number of jars, or preferably Thermos bottles, of water at various temperatures. One can contain ice water, one water that is as hot as the tap will provide, and others at temperatures in between. It is perfectly all right to have some jars with identical temperatures. Label the jars with numbers, one through however many groups you have.

Give each group a jar. Ask the students to measure the temperature of the water in their jar and enter the measurement on their paper next to the number of the jar. Then trade jars with another group.

While this activity is going on, walk around the room and provide individual attention where it is needed.

Measuring Heat

When you are satisfied that all students can read a thermometer, terminate this activity and pass out the worksheets. Set up a station where students can safely heat their containers. This may be an electric hot plate, a can of Sterno, or a laboratory burner. Supervise this station to remind students that heating the water to boiling is NOT the object. In some classes, you will already have run out of time and will have to carry over the lesson to the next meeting of the class.

Measuring Heat

In this investigation, you will learn how to measure heat. To do the investigation, you need:

☐ a thermometer marked with the Celsius scale

☐ a graduated cylinder

☐ a Pyrex® beaker, metal pan, or tin can

☐ water

☐ a source of heat, such as laboratory burner. You can share a heat source with others.

Do you have everything you need?

You are required to memorize the definition of a calorie: A calorie is the amount of heat needed to raise the temperature of one gram of water one degree Celsius. Remember, a mass of one gram of water takes up a volume of one milliliter.

Procedure

Step One: Measure out some water, using the graduated cylinder, and put it in your container. Record

the volume of water ______________ milliliters

Step Two: Remember, one milliliter of water has a mass of one gram. What is the mass of the water in your container?

______________ grams

Step Three: Use your thermometer to measure the beginning temperature of the water.

______________ degrees Celsius

Step Four: Take your container to the heat source and transfer some heat to the water. Transfer enough heat to make a noticeable change in the temperature of the water. Don't let the water get so hot it could burn you.

Step Five: Measure the temperature of the water now.

______________ degrees Celsius

Step Six: Now you are ready to calculate how many calories of heat were transferred to your container.

(temperature difference in degrees Celsius) X (mass of water in grams) = calories

end temperature = ______________ °C

beginning temperature = – ______________ °C

temperature difference= ______________ °C

mass of water in grams = X ______________ grams

______________ calories

Heat Flows

Objectives

This lesson contributes to students' understanding of the following concepts:

Energy cannot be created or destroyed.

Energy can be measured.

Heat flows from hotter areas to colder areas.

The universe tends to become the same temperature throughout.

The greater the difference in temperature between two objects, the faster the flow of heat between them.

Format of the Lesson

Discuss whether heat is destroyed when objects cool

Explain investigation

Conduct investigation

Discuss results

Discuss implications for energy flow in universe

Investigate rate of heat flow

Discuss results

Materials Needed

container with a lid, such as a half-gallon plastic container. The less conductive, the better, so plastic is better than metal. One per group.

tin can the small, 6-ounce, pull-tab cans that fruit juice comes in. One per group.

masking tape one roll.

old newspapers corrugated cardboard, or other insulating materials.

thermometer graduated in degrees Celsius.

water at room temperature. If it is warmer than room temperature, it will lose heat to the surrounding air during the investigation; and if it is colder than room temperature, it will gain heat from the air. This additional flow can confuse the students.

graduated cylinders 100 or 250 mL. One per group. You can substitute bottles that you have calibrated yourself.

gallon jugs to store water in advance so that it will be at room temperature. Four jugs are plenty.

hot plate or other heat source.

large beaker or pan with a pouring lip, for heating water which you will dispense to the students.

graduated cylinder for measuring hot water dispensed to students. One.

clock with sweep second hand, wristwatches, or stopwatch.

activity sheet **Tracking the Elusive Calorie**, one per student.

worksheet **Calculation of Heat Flow**, one per student.

activity sheet **Does the Size of the Temperature Difference Affect the Rate of Heat Flow?** one per student.

worksheet **Calculation of Rate of Heat Flow**, one per student.

Preliminary Discussion

Ask the class, if we had a hot electric iron here in the room, and we turned it off, what would happen to the iron? (ANS: It would grow colder.) What happened to the energy in the iron? Students may suggest a variety of explanations, or they may all recognize that the heat flowed into the room air. In either case, suggest that this is a hypothesis: that when an object cools, no energy is destroyed, but simply lost as heat transferred to some other object.

We can test this hypothesis by measuring the heat flowing out of an object and also the heat flowing into the object's surroundings. Will the amount of heat the object has lost be the same as the amount of heat gained by the surroundings?

Review how we measured heat: measure the mass and the change in temperature.

Pass out the worksheets and the materials.

Handling the Hot Water

In this investigation, students need a tin can three-quarters full of very hot water. You will provide this. One way is by walking around the classroom with a pitcher of hot water, measuring it with a graduated cylinder, and pouring it into the tin cans at the tables. An alternate procedure is to dispense water to the students at some central station. In the latter case, have students make hot pads from layers of newspaper to make it easier to carry the hot cans back to their tables.

After the Investigation

On chalkboard, make two headings:

HEAT LOST BY WATER IN TIN CAN

HEAT GAINED BY WATER IN CONTAINER

Ask the groups for their results and enter them in the columns. If all the students used identical containers and tin cans, find an average for the class.

Does the heat lost by the hot water match the heat gained by the room temperature? How big might our measurement errors have been? What are some other factors that might have affected our results?

We can conclude that heat does flow from hot objects to cooler ones. Does heat ever flow from cold objects to hot ones?

The "Heat Death" of the Universe

If you have a sealed room in which there are some hot objects, like an iron, and some cold objects, like a glass of ice water, what will happen as time passes? (ANS: Everything in the room will become the same temperature. The cold things will warm up and the hot things will cool off.)

What about in the whole universe? There are hot things and cold things, obviously. What happens as time passes? (ANS: Everything tends to become the same temperature.) The whole universe keeps warming up as other forms of energy are converted to heat and the heat spreads to cooler parts of the universe. It may be that, in billions of billions of years, long after the sun has gone out, the universe will be all the same temperature. This is certainly the tendency of heat flows.

Yet we see lots of exceptions. Consider this idea in relation to our planet, Earth. Is everything on earth the same temperature? What seems hotter than average? Is an energy input needed to make such things hotter than most things? Discuss some specific examples, like the polar caps or the warmth of living mammals or volcanoes. Point out that, in each case, we can identify an input of energy. A constant supply of energy is always needed to prevent everything from becoming the same temperature.

In advanced classes, you may wish to go on to discuss the concept of entropy. See the references in **Additional Resources**, at the end of this unit, for help in doing this.

By this time you have probably reached the end of the period. This is a convenient point at which to break.

Investigating the Rate Of Heat Flow

Review the previous investigation. In doing so, it is useful to introduce two new words: *source*, meaning the matter from which heat is flowing; and *sink*, meaning the matter to which the heat is flowing. In our investigation, the source was the tin can of hot water, and the sink was the room-temperature water in the container.

Point out to the class that in the investigation we also measured a rate, namely, calories per ten minutes. On what factors does this rate depend? For example, we might guess that the hotter the source is, the faster the rate of heat flow to the sink will be. Let's do another investigation to determine how differences in temperature affect the rate of heat flow.

Pass out the worksheet, **Does the Size of a Temperature Difference Affect the Rate of Heat Flow?** and the necessary materials, which are identical to those used in the previous investigation.

Post-Activity Discussion

On the chalkboard, make a graph comparing difference in temperature (in degrees Celsius) with rate of heat flow (in calories per minute). What, if any, conclusions can we reach?

Projects for Independent Investigation

1. In a refrigerator, heat is transferred from the cold interior of the refrigerator to the warm kitchen. In other words, there is a heat flow from cold to warm! How can this be possible? Do some research on how refrigerators work and report to the class.
2. If you turn down the thermostat on your water heater, you will save gas (or electricity). But how can this be? You will still be taking baths or showers at the same temperature, using the same amount of water. In other words, there will be just as many Btu's in the bathtub as before. To get those Btu's, you will have to mix a greater proportion of hot water to cold water at the faucet because the hot water is not as hot as it used to be. You're using cooler hot water but more of it. This being so (and it is) how can it be possible that less fuel is being used (which is also true)?
3. Imagine a woman who takes her coffee as hot as possible, and with cream. (The cream is cold.) She is in a restaurant. The waiter pours the coffee, but the woman doesn't want to drink it until ten minutes from now, when her dessert comes. She turns and asks you: "In order for my coffee to be as hot as possible ten minutes from now, should I put the cream in now, or wait ten minutes and put it in when I'm ready to drink the coffee?" Test your answer experimentally.

Tracking the Elusive Calorie

When something cools off, what happens to the heat? Is it destroyed? Let's investigate.

To do this investigation, you need:

☐ a worksheet called **Calculation of Heat Flow**

☐ a large glass or plastic container, like a beaker

☐ a Celsius thermometer

☐ some old newspapers or other insulation

☐ masking tape or rubber bands

☐ some room-temperature water

☐ a small tin can

☐ a graduated cylinder

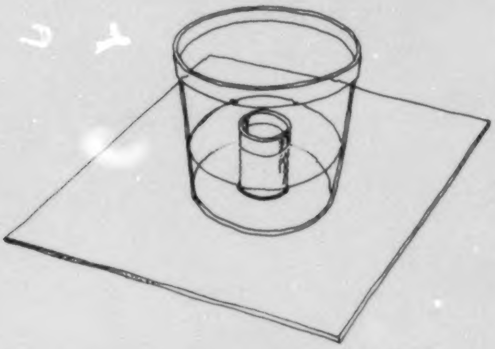
☐ some hot water that you will get from your teacher during the investigation

Do you have everything you need?

Procedure

Before beginning, read all the steps and the worksheet.

Step One: Check to be sure the tin can is small enough to stand upright inside your large container when a lid is put on the large container.



Step Two: Insulate the large container as well as you can. Try wrapping layers of newspaper around it loosely, held in place with masking tape or rubber bands. Put some corrugated cardboard under it. Make an insulated lid for the container out of cardboard.

Step Three: Measure the temperature of the air in the room. Record the measurement on your worksheet.

Step Four: Add room-temperature water to the large container until the water is about half as deep as your tin can is high, using the graduated cylinder to measure how much water you are adding. Record the volume of water on the worksheet. (Don't put the tin can into the container yet!)

Step Five: Measure the temperature of the water in the container. It should be about room temperature. Record the measurement on the worksheet.

Step Six: Take your tin can to your teacher. You may want to fold up some newspaper to make a hotpad for carrying the can. Your teacher will pour a measured volume of hot water into the can. Carefully take the can back to your table and record the volume on the worksheet.

Step Seven: Quickly measure the temperature of the hot water. Leave the bulb of the thermometer in the hot water while you are reading the thermometer. Record your measurement on the worksheet.

Step Eight: Set the tin can full of hot water in the container of room temperature water. It's OK if the can floats a little as long as no water spills out of it. Put the lid on the container.

Step Nine: Let about ten minutes go by.

Step Ten: Take the lid off the container. *Gently* stir the water in the tin can with the thermometer, then read the temperature of the water in the tin can. Next measure the temperature of the water in the container. Record the temperature measurements on the worksheet.

Step Eleven: Put the materials back where they belong.

Step Twelve: Do the calculations on the worksheet.

Calculation of Heat Flow

1. Heat Lost by Hot Water in Tin Can

beginning temperature = ____________ °C

end temperature = − ____________ °C

change in temperature = ____________ °C

volume of water = ____________ milliliters ≅ x ____________ grams

heat lost by hot water = ____________ calories

2. Heat Gained by Room-Temperature Water

end temperature = ____________ °C

beginning temperature = − ____________ °C

change in temperature = ____________ °C

volume of water = ____________ milliliters ≅ x ____________ grams

heat gained by room-temperature water = ____________ calories

Does the Size of a Temperature Difference Affect the Rate of Heat Flow?

We can describe the rate of a flow of heat in calories per minute. Suppose we have two setups in which heat is flowing from a hot source to a cold sink. The setups are identical, except that in one the difference between the temperatures of the source and sink is very great; in the other, they are almost the same temperature. Do you think the heat will flow at the same rate in both setups? Or do you think the rate of heat flow will differ?

In this activity, you will make one setup, and other groups will make other setups identical to yours except for the temperature of the hot water. That way we can obtain measurements of the rate of heat flow at various differences in the temperatures of the source and sink.

(We will always start with room-temperature water in the container, since that minimizes heat flow between the container and the surrounding air.)

To do this investigation, you need:

☐ a small tin can

☐ a thermometer

☐ some old newspapers or other insulation

☐ masking tape

☐ a container with a lid

☐ some water

☐ a graduated cylinder

☐ clock or watch with a sweep second hand

Do you have everything you need?

Procedure

Before beginning, read all the steps.

Step One: Insulate your container as well as you can. Try taping newspaper around it loosely. Put some corrugated cardboard under it.

Step Two: Measure some water and put it into the container until the depth of the water in the container is about half the height of your tin can. Record the volume of water on the worksheet.

Step Three: Measure the temperature of the water in the container. It should be about room temperature. Record the measurement on the worksheet.

Step Four: Take your tin can to your teacher, who will fill it with a measured quantity of hot water. Record the volume. Carefully take the can back to your table.

Step Five: Quickly measure the temperature of the hot water. Record your measurement on the worksheet.

Step Six: Put the tin can full of hot water into the container of room-temperature water. Put the lid back on the container. *Start timing.*

Step Seven: Let exactly ten minutes go by. Then take the lid off the container and quickly measure the temperatures of the water in the tin can and the water in the container. Stir the water with the thermometer before doing so. Measure the temperature of the water in the tin can first. Record your measurements.

Step Eight: Do the calculations on the worksheet.

Calculation of Rate of Heat Flow

1. Heat Lost by Hot Water in Tin Can

beginning temperature = ____________ °C

end temperature = – ____________ °C

change in temperature = ____________ °C

volume of water = ____________ milliliters ≅ x ____________ grams

heat lost by hot water = ____________ calories

2. Rate of Heat Flow

____________ calories in 10 minutes =

____________ calories per minute.

3. Temperature Difference

beginning temperature of source = ____________ °C

beginning temperature of sink = – ____________ °C

temperature difference = ____________ °C

Notes

Comparing Two Units

Objectives

This lesson contributes to students' understanding of the following concepts:

Units of measurement are organized into systems.

The customary system widely used in the United States differs from the International System of Units (SI) used throughout the world.

Anything measurable in one system can be measured in the other.

One Btu is the amount of heat needed to raise the temperature of a mass of one pound of water one degree Fahrenheit (at 39.1°F).

A measurement made in one system of units can be converted to a measurement in another system of units.

One Btu is equivalent to approximately 252 calories.

Format of the Lesson

Discuss existence of different systems of measurement

Measure the length of an object in inches and centimeters

Calculate a conversion factor

Identify properties measured in measuring heat

Define Btu

Conduct activity

Materials Needed

chalkboard

thermometers one for each group of students. These thermometers must be either dual scale (both Celsius and Fahrenheit), or two separate thermometers, one Celsius and one Fahrenheit, are needed.

yardstick

meterstick

anything a bit less than a yard long for the students to measure.

beakers or tin cans, any size larger than a pint, one per group.

graduated cylinders or measuring cups, one per group.

measuring cups at least pint size, one per group.

worksheet **How Many Calories in a Btu?**

Preliminary Discussion

Show the students a yardstick and a meterstick. Ask them what they are. If this has not been part of their education, explain that most of the world measures things using the International System of Units (commonly referred to as the metric system), in which lengths of things are measured in meters. We often use the English system, measuring lengths in inches, yards, and miles. Demonstrate that the meter is divided into 100 subdivisions, called centimeters, and each centimeter into ten millimeters.

We hope that this is merely review for the students, since what we are about to do (a comparison of the systems) is not the most effective way of introducing the metric system, any more than constant comparison with English is the best way to learn a foreign language. Here, we need to make this comparison to help students see that the physical reality being measured remains the same no matter what system of units is used and, therefore, measurements in different units can be equivalent.

Show the students any physical object one dimension of which is a few inches less than a yard. Give one student the yardstick and ask her to measure this dimension in inches. Record the measurement on the chalkboard, being sure to include the name of the unit, "inches."

Ask another student to measure the object in centimeters. Write that measurement on the board. Ask if we could use these measurements to estimate how many centimeters there are in an inch. Following the students' directions, divide the number of centimeters by the number of inches to get approximately 2.5.

Calories and Btu's

Put the following heading on the board:

MEASURING HEAT IN METRIC
AND CUSTOMARY UNITS

Ask the name of the unit we use to measure heat. (ANS: calorie.) Make that a heading. Ask what we need to know to measure calories. (ANS: Mass and temperature.) Make those headings on the left, as shown.

Ask what units are used to measure mass when we are calculating calories. (ANS: Grams.) Enter grams on the chart. Ask what units are used to measure mass in customary units. (ANS: Ounces, pounds, tons.) Choose pounds and enter that in the chart.

Ask in what units we measure temperature when we are measuring calories. (ANS: Degrees Celsius.) And in customary units? (ANS: Degrees Fahrenheit.)

The chart should now look like the one below.

MEASURING HEAT IN METRIC
AND CUSTOMARY UNITS

	Metric	Customary
Heat	calorie	???????
Mass	gram	pound
Temperature	°Celsius	°Fahrenheit

Tell the students that American and British engineers needed a unit of heat, too, so they defined one using their customary units. It is called the British thermal unit, or Btu, and it is defined as the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit (at 39.1°F, the point of maximum density, but we will neglect this).

If I measured my head size in inches, could I convert that to centimeters for my friend in France who wants to send me a hat? How? Could he convert his size to inches for me? How?

Suppose I measure a quantity of heat in calories. Could I convert that to Btu's? (ANS: Yes, if you knew how many calories there were in a Btu.)

Let's do an investigation to try to find a factor for converting Btu's to calories.

How Many Calories in a Btu?

In this investigation, you will learn about another unit used to measure heat, and compare that unit to the calorie.

To do the investigation, you will need:

- ☐ thermometer that measures in degrees Celsius
- ☐ thermometer that measures in degrees Fahrenheit. (Some thermometers are marked with two scales, so you may only need one thermometer.)
- ☐ graduated cylinder
- ☐ pint measuring cup
- ☐ beaker or tin can
- ☐ source of heat

Do you have everything you need?

Procedure

Step One: As you go along, enter your measurements on the form at the bottom of this page.

Step Two: Measure out one pint of water and put it in the beaker. One pint of water has a mass of about one pound. Now measure that same water again using the graduated cylinder. One milliliter of water has a mass of how many grams? Enter the measurements on the worksheet.

Step Three: Measure the temperature of the water in degrees Celsius and also in degrees Fahrenheit. Enter the measurements on the worksheet.

Step Four: Heat the water. Don't try to boil it, just get it warm.

Step Five: Measure the new temperature of the water in degrees Celsius and also in degrees Fahrenheit. Enter the measurements on the worksheet.

Step Six: Do the calculations below.

Calculations

(difference in temperature in degrees Celsius) x (mass in grams) = calories

(difference in temperature in degrees Fahrenheit) x (mass in pounds) = Btu's

	Metric	Customary
end temperature =	______ °C	______ °F
beginning temperature =	− ______ °C	− ______ °F
temperature difference =	______ °C	______ °F
mass =	x ______ grams	x ______ pounds
heat added to water	______ calories	______ Btu

If ______ calories = ______ Btu

then ______ calories = 1 Btu.

Notes

Changing Motion to Thermal Energy

Objectives

This lesson contributes to students' understanding of the follow concepts:

Energy is not created or destroyed.

Friction converts mechanical energy to thermal energy.

When a moving object comes to rest, its mechanical energy has often been converted to thermal energy.

Format of the Lesson

Discuss: can mechanical energy disappear?

Group activities

Reports from groups

Summary discussion

Materials Needed

In this lesson, the students are divided into groups for part of the period, and each group performs a different activity. Before class, sort the materials by activity, perhaps into boxes. Needed for many of the activities are:

thermometers one for each group.

water and a means of measuring it out in milliliters, such as one graduated cylinder, at a central location.

wall clock

Shot Tube

3/4-inch PVC plastic pipe one piece, 1 meter long. PVC pipe is available from building supply stores in 10-foot pieces for 90¢. It can be easily cut with a handsaw. If you have enough students, consider making different sized pipes, say, 0.5 meter, 1 meter, and 2 meters long, and see if there is a difference in temperature rise.

lead shot or BB's sporting goods stores will usually sell shot only in 25-pound bags. One dollar's worth of split shot fishing-line sinkers will do, or 1,500 air-rifle BB's for about $1.50.

corks to fit the above pipe, two solid and one 1-hole, the hole the right size to accept the thermometer. One of these corks can be replaced, and a potential spill avoided, by gluing an end cap (30¢) on one end of the pipe. Caps are available from the pipe supplier.

Superball

Superball or hard plastic or rubber ball. A sponge rubber ball won't work. With an ordinary bit, drill a hole in the ball big enough to accept the bulb of the thermometer.

Sand Bottle

plastic bottle with a cylindrical configuration, like the ones glue comes in. Bottles with pinched middles don't work.

sand a cup full.

Metal Fatigue

wire coat hanger cut into 25-cm pieces.

Bicycle Brake

bicycle

plastic film-can the kind 35mm color film comes in. Photo dealers, who remove these cans before sending the film to the laboratory for processing, will usually give local teachers any reasonable number.

Rumford Revisited

jar lid with nuts glued in take a plastic jar-lid, preferably with a knurled rim, such as comes on a Sanka jar, and remove the paper liner to make a small flat cup. Glue five #8 steel nuts to the bottom of the cup with silicone glue-sealer. Let dry overnight.

hand drill borrow from the school shop; $10 if you purchase even an inexpensive one.

3/8-inch bit try to get an old dull one.

Cup and Sandpaper

styrofoam cup

silicon-carbide "wet or dry" sandpaper, medium grit about 50¢ a sheet.

40-d common nail 7¢.

hand drill borrow from school shop.

Copper Cup

cap for 3/4-inch copper tubing available from building supply houses, about 70¢.

modeling clay small piece.

hand drill borrow from school shop; $10 if you purchase even an inexpensive one.

40-d common nail 7¢.

Establishing a Focus

Tell the class that today we will be thinking about mechanical energy. Ask the students to give some examples of mechanical energy. Point out that, if we follow this mechanical energy, it often **seems** to disappear. For example, when a falling object lands, the mechanical energy often seems to have vanished. If energy cannot be created or destroyed, this can't really be the case. Today, we will do some investigations to find out what happens to mechanical energy.

Setting Up the Activity

Divide the class into appropriate groups. (Three of the activities require some care: it is easy to break a thermometer if it is not very carefully inserted into the Superball or through the one-hole cork, and horsing around with the upside-down bicycle is hazardous.)

Point out where water can be obtained and measured.

Distribute the activity sheets and the materials.

During the activities, circulate among the students and supervise the riskier uses of thermometers. Urge students to take turns. Keep that mechanical energy coming during the investigation!

Notes on the Activities

Shot Tube

If we added more BB's, would we get a greater rise in temperature?

This activity can be used to estimate a conversion factor between work and heat. To be able to do this later, save the data on the number of times the BB's fell. Have students estimate the distance the BB's fell. (Note that it is not the length of the tube or the distance beween cork bottoms. Why?) Count the number of BB's or weigh them.

Superball

Be sure the group chooses an appropriate area in which to bounce the ball.

Metal Fatigue

Save the pieces of wire; they can be used to make thermopiles.

Bicycle Brake

Check the students doing this activity to be sure that they are not wearing loose clothing, such as a scarf or necktie; and that any long hair is well out of the way of the revolving wheel. You may wish to mention to the group that the safety standard rule in factories and machine shops is : No long loose clothing near revolving machinery.

Later, after all the reports, you may have a chance to discuss the implication of this activity for car brakes.

Rumford Revisited

Does anyone know why the activity has this title?

Does the sharpness of the bit make any difference? How could you find out?

Cup and Sandpaper

What could you do to minimize the heat flow up the nail?

Copper Cup

Unlike the sandpaper in the cup, this activity did not use an abrasive. Does the use of an abrasive affect transformation of mechanical energy to thermal energy?

If we repeated the experiment with oil instead of water, what would happen? (Note that the specific heat of oil is lower than that of water, which would have to be taken into account.)

After the Activities

Call on each group to give its report.

Summarize that when mechanical energy seems to disappear, it has often been transformed into thermal energy.

Ask the students how much work they think it takes to, say, heat a pot of tea to boiling? Did they put out a lot of effort in the investigations? Did their efforts yield very much heat?

If time remains, you may wish to discuss the following questions:

1. When a car stops, where does the mechanical energy go? Why do brakes heat up?

2. When a falling object hits the floor, where does the mechanical energy go?

A Further Topic: Quantifying Work to Heat

After students have learned how to measure mechanical energy, you may want to consider conducting an investigation to find the size of the conversion factor from some work unit (we suggest the joule) to a quantity-of-heat unit such as the calorie. Various pieces of elegant apparatus are available from the scientific supply houses for conducting such an experiment, but for the most part they are expensive. Exceptions are the shot tube, which is described here; and an apparatus offered by Eduquip-Macalaster, which we have not tested. We would be interested in hearing from anyone who has.

Shot Tube

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

☐ plastic pipe, one piece, 1 meter long

☐ thermometer

☐ three corks to fit pipe (one with a hole big enough for the thermometer to fit through)

☐ lead shot, or BB's

Procedure

Step One: Put a cork in one end of the piece of plastic pipe. Pour enough BB's into the tube to fill it to a depth of 4 cm. Count how many BB's you used.

Step Two: Carefully put the thermometer through the one-hole cork, with the thermometer bulb at the narrow end of the cork. Place the cork with the thermometer in the open end of the tube. Slowly tilt the tube so the BB's run **slowly** down the tube and surround the thermometer bulb.

Step Three: Wait two minutes and record the reading on the thermometer.

Step Four: Invert the tube so the BB's run back to the other end. Remove the cork with the thermometer and put in a solid cork.

Step Five: Invert the tube so that the BB's fall from one end of the tube to the other. Do this again and again, back and forth, for five minutes. Count and record the number of times the BB's fall from one end of the tube to the other.

Step Six: At the end of five minutes, replace the solid cork with the cork with the thermometer in it. Slowly invert the tube so that the BB's surround the bulb of the thermometer. Record the thermometer reading.

Step Seven: Put all materials back where they belong. Pick up any spilled shot.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Superball

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

☐ thermometer

☐ Superball, or hard rubber ball, with a hole drilled halfway through it, big enough to accept the bulb of the thermometer

Procedure

Step One: Very, very carefully place the bulb of the thermometer into the hole drilled in the ball. Record the temperature. Remove the thermometer.

Step Two: Bounce the ball vigorously for about five minutes. Take turns. Bounce it against a hard surface, using the palm of your hand as a paddle.

Step Three: After five minutes, again insert the bulb of the thermometer into the drilled hole. Record the temperature.

Step Four: Put materials back where they belong.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Sand Bottle

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

- ☐ plastic bottle
- ☐ thermometer
- ☐ dry sand

Procedure

Step One: Fill the plastic bottle about half full of sand.

Step Two: Gently insert the bulb of the thermometer into the sand. Wait about two minutes, then record the temperature.

Step Three: Place the cap on the bottle. Shake it back and forth for five minutes. Don't stop. Take turns.

Step Four: At the end of five minutes, remove the cap and place the thermometer bulb into the sand. Wait two minutes, and record the temperature.

Step Five: Wipe the thermometer clean and put it away. Leave the sand in the bottle.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Metal Fatigue

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

☐ test tube

☐ wire coat hanger

☐ water

☐ thermometer

Procedure

Step One: Pour 1 mL of water into the test tube. Place the thermometer in the water and measure its temperature. Record the temperature. Remove the thermometer.

Step Two: Bend the section of coat-hanger wire so the bend is in the middle. Keep bending it back and forth until it breaks.

Step Three: Immediately place the broken ends of the wire into the water. Place the bulb of the thermometer into the water. Record the temperature.

Step Four: Put the materials back where they belong. Save the broken wires for future experiments.

Questions

Choose one or more speakers to tell the class what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Bicycle Brake

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

☐ bicycle

☐ plastic film-can

☐ thermometer

☐ water

Procedure

Step One: Pour 5 mL of water into the plastic container. Record the temperature of the water.

Step Two: Place the bicycle upside down so it rests on the seat and the handlebars.

Step Three: Move the pedal with your hand to build up speed on the drive wheel. (Be extremely cautious with moving parts. Keep loose clothing and long hair away from the wheel and chain!)

Step Four: Hold the capped container with water in it gently against the tire so that the wheel eventually comes to a stop. Repeat this procedure several times.

Step Five: After the last time, record the temperature of the water in the container.

Step Six: Put the bicycle away.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Rumford Revisited

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

☐ jar lid in which several nuts are glued

☐ thermometer

☐ water

☐ hand drill with 3/8" steel bit

Procedure

Step One: Pour 10 mL of water into the lid. Record the temperature of the water.

Step Two: Use the hand drill. Place the bit over the hole in the nut. Drill for five minutes. If you get through one nut, move on to another. Take turns, but keep drilling!

Step Three: At the end of the five minutes, record the temperature of the water.

Step Four: Put materials away.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Cup and Sandpaper

To do this activity, you will need the following materials. Check to be sure you have them before beginning the activity.

☐ styrofoam cup

☐ silicon-carbide "wet or dry" sandpaper

☐ hand drill

☐ large nail, "spike"

☐ water

☐ thermometer

☐ scissors

Procedure

Step One: Cut a circle from the silicon-carbide sandpaper just large enough to fit into the bottom of the styrofoam cup. Press in place.

Step Two: Pour about 10 mL of water into the cup. Measure the temperature of the water and record your measurement.

Step Three: Open the chuck of the drill, place the pointed end of the nail in it, and tighten the chuck just as you would if the nail were a bit.

Step Four: Place the head of the nail against the silicon-carbide sandpaper. Turn the drill vigorously. Take turns. Do this for five minutes.

Step Five: At the end of five minutes, record the temperature of the water.

Step Six: Clean up. Put materials away.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Copper Cup

To do this activity, you will need the following materials. Check to be sure you have everything before beginning the activity.

☐ 3/4" copper cap for copper tubing

☐ piece of clay

☐ thermometer

☐ hand drill

☐ large nail

☐ water

Procedure

Step One: Press the closed end of the copper cap down into the clay. The open end should be even with the top of the clay.

Step Two: Pour 2 mL of water into the cap. Record the temperature of the water.

Step Three: Open the chuck of the drill, place the pointed end of the nail in it, and tighten just as you would if the nail were a bit.

Step Four: Place the head of the nail against the bottom of the cap. Turn the drill for five minutes. Take turns, but don't stop.

Step Five: At the end of the five minutes, record the temperature of the water.

Step Six: Clean up. Put the materials away.

Questions

Choose one or more speakers to report to the class on what your group did. Describe briefly the apparatus you used and the steps you took, and your measurements. What is your explanation for what happened? Did you observe any energy transformations?

Notes

Measuring Mechanical Energy

Objectives

This lesson contributes to the students' understanding of the following concepts:

Matter at rest stays at rest and matter in motion remains in motion with the same direction and speed, unless acted on by a force.

A force applied to a mass accelerates it.

Force can be described in terms of a mass and acceleration.

Work can be defined by force and the distance through which the force moves matter.

Vocabulary

force
accelerate
newton
work
joule

Format of the Lesson

What is mechanical energy?

Equivalence of energy possessed by a moving object and energy needed to move it

Force

How can we define a unit of force?

Definition of the newton

Force of gravity

Work

Activity

Materials Needed

spring balance 0 to 20 newtons. A suitable balance is Eduquip-Macalaster stock #0000383, $3.00, or Fisher Catalog #S40137, $3.25. You can convert spring balances calibrated in pounds to newtons by pasting a self-adhesive file folder label over the old calibrations and marking new calibrations using 1 newton = 0.225 pounds. One per group.

boards width of one roller skate, and various lengths. Nominal one by three, surfaced four sides, is good, and costs about 75¢ a foot.

bricks three or four per group 27¢.

roller skates or the plastic carts made especially for this purpose available from several supply houses.

metersticks

string

worksheet **Measuring Work**, one per student.

What Is Mechanical Energy?

Since the beginning of the unit we have been talking about mechanical energy. Ask the students to describe what we mean by mechanical energy.

Does a moving object possess energy? How do we know? (ANS: One way: its motion can be converted to heat.)

Is energy required to move things? (ANS: Yes.)

Knowing that energy is conserved, how do you think the energy possessed by the moving object compares with the energy required to move it? (ANS: The same.)

What makes objects move? Elicit simple, concrete examples. Summarize that, in these examples, a push or pull was needed to move the object.

The Force Is with Us

The physicist needs exact definitions. She cannot talk vaguely about pushes and pulls. So we define something we call force.

Show the class the spring balance marked in newtons. Tell them this is an instrument that can be used to measure force. Hook the hook of the balance over a student's finger and pull with a force of about two newtons. Tell the class you are applying a force to the finger. Ask the student to read the balance. (It may or may not have the word newton on it; the student can read it as one "en.") Increase the pull to five newtons. Ask the student if he can feel the increase in force. What is the reading now?

Defining a Unit of Force

Tell the class that the instrument is calibrated in a unit called a "newton." Force can be measured in newtons. Can anyone guess where this word came from? (ANS: From Sir Isaac Newton, the English physicist.) How can we define a unit of force? By what a force does; namely, accelerate something.

To understand how force is defined, we first have to recall what we know about moving objects. Objects have **inertia**. An object that is moving tends to keep moving; an object at rest tends to stay at rest. A ball thrown in empty space would just keep on moving until something stopped it. No force would need to be applied to keep it moving.

In our day-to-day experience, moving things do not keep moving. If you push a car, you more or less have to keep pushing to keep the car moving. But the force you have to continue to apply is just to overcome air resistance, friction, the flexing of the rubber in the tires, and so forth.

What happens when a force is applied to an object and there isn't any friction, air resistance, etc.? The object won't just move; it will continue to move faster and faster. It **accelerates**. As long as the force continues to be applied, the object will continue to accelerate.

Defining the Newton

The newton is the amount of force which, if applied to a mass of one kilogram, will accelerate it one meter per second per second.

So suppose out in space, in a vacuum, a force of one newton is applied to a mass of one kilogram.

At end of the:	the mass will be traveling at:
first second	one meter per second
second second	two meters per second
third second	three meters per second

And so on, as long as the force continues to be applied the velocity of the mass will keep increasing.*

---

*Ignoring relativistic effects.

Force of Gravity

Hold out a brick and drop it. Ask the students to describe what happened. Ask whether the brick accelerated. (ANS: Yes.) The farther it fell the faster it traveled, until air resistance slowed it. (How could we test this assertion experimentally?)

For a mass to be accelerated, a force must be applied. What force accelerated the brick? (ANS: Force of gravity.)

The Difference Between Force and Energy

Hang a weight on the spring balance and suspend it from any convenient inanimate object, like a ring stand. Ask the class if a force is being exerted. (ANS: It is; we can tell by the scale.) Is energy being supplied? (ANS: No.)

Ask some students to push on the wall with all their might. Is a force being exerted? (ANS: Yes.) Is energy being expended? Not in the physicist's sense. (It is true that the human being doing the pushing is metabolizing carbohydrate, but this is not relevant. A stick leaning against the wall would also exert a force.)

Work

Force is not energy. But we know that, when a force is applied to a mass, and the mass moves, energy is being supplied. There is mechanical energy in the moving mass. If we describe the strength of the force, and the distance over which the force is applied, we have described a quantity of energy. This energy is given the name **work**.

Defining a Unit of Work: the Joule

WORK = FORCE x DISTANCE

If the force is in newtons, and the distance in meters, then the work is in joules (pronounced jewels). So we can define a unit of work as a newton acting through a distance of a meter.

The joule is the fundamental unit of energy in the International System of Units. (Power at the rate of one joule per second is called a watt!)

Setting Up the Investigation

Propose to the class that we do an investigation in which we will practice measuring work. We will measure the work needed to raise a brick in two different ways.

Divide the class into groups, pass out the worksheets, and make the materials available.

For Discussion After the Activity

Compare the results of the different groups. Did it take the same amount of work to raise the brick vertically as it did on the ramp? Did the length of the ramp make any difference?

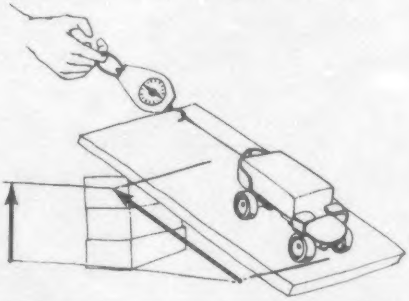
Projects for Independent Investigation

1. Choose one of the simple machines. Show how it does not change the amount of work required to raise a mass a given distance. Why, then, is it useful? What does it change?

Measuring Work

In this activity, you will lift a mass by using a ramp, and then lift the mass straight up to the same height. Make a prediction: will the amount of energy needed be the same, or different. Why do you think so?

To do this activity, you will need:



- ☐ bricks
- ☐ a spring balance calibrated in newtons
- ☐ a board
- ☐ a meterstick
- ☐ a roller skate
- ☐ string

Do you have everything you need?

Some Definitions and a Formula

A newton is the quantity of force that will accelerate a mass of one kilogram at a rate of one meter per second per second.

A joule is the work done by a force of one newton moving through a distance of one meter.

Work = force x distance (work in joules = force in newtons x distance in meters).

Step One: Using the board and all but one of the bricks, make a ramp like that shown in the illustration.

Step Two: Put a brick on the roller skate. How much force is needed to move the brick up the ramp?

________________ newtons.

Step Three: Measure the distance any particular point on the brick moves in going from the bottom of the ramp to the top. Notice that this is NOT the length of the ramp.

________________ meters.

Step Four: Calculate the work done in moving the brick up the ramp. (force x distance = work).

__________ newtons x __________ meters = __________ joules

Step Five: Measure the force needed to lift the brick and roller skate vertically. ________________ newtons.

Step Six: Measure the distance the brick traveled vertically when it went up the ramp. ________ meters.

Step Seven: Calculate the work done in lifting the brick (plus roller skate) the same distance vertically as it was lifted by moving it up the ramp. (force x distance = work)

__________ newtons x __________ meters = __________ joules

Questions

1. How did the quantities of work compare? Why?

2. Suppose that instead of using a roller skate we had dragged the brick up the ramp. Would more work have been done? Give reasons for your answer.

Measuring Electricity

Objectives

This lesson contributes to students' understanding of the following concepts:

Energy can be measured.

Electricity can be measured.

We measure electricity when we use it in our homes.

Vocabulary

volts

amperes

amps

watts

kilowatts

kilowatt-hours

Format of the Lesson

Measuring energy

Detecting electricity

Using electricity

Examining rating plates

Assignment

Materials Needed

light bulbs different sizes, marked with wattages.

small appliance optional, with a rating plate.

overhead transparency of rating plates.

worksheet

checklist **Home Appliances.**

Measuring Energy

Review with the class the method they have learned for measuring one form of energy, heat.

Point out some of the aspects of measuring.

Units We had to have well-defined units. What were they? (ANS: The gram, the degree Celsius, the calorie; or the pound, the degree Fahrenheit, the Btu.)

Measurement Technique We had to have a way of measuring those units, like a thermometer for the temperature, and a balance for mass. (For grams of water, we took advantage of the fact that one milliliter of water has a mass of almost exactly one gram.)

So we can measure heat. Do you think it is possible to measure other kinds of energy? (ANS: Yes, sure.)

Why Measure?

One of the first reasons people became interested in measurement was that measurement was necessary in bartering goods and, later, in buying and selling things. Your family buys energy. You buy gasoline by the gallon, for example. What other kinds of energy do you buy? (ANS: Electricity, gas; perhaps propane, coal, wood, or other forms.)

Since we buy electricity, we must be able to measure it. Let's do some detective work and see if we can find the units that are used to measure electricity.

Show the class some light bulbs. Point out that some bulbs give more light than others. When we're describing a light bulb, how do we say that this one (indicate the 100-watt bulb) is bigger or brighter than this one (a 40-watt bulb)? (ANS: Watts. One is a 40-watt light bulb and the other is a 100-watt.)

Point out to the class that the markings on the light bulbs indicate this answer is correct; for some reason, the bulbs have the word "watt" on them. Watt must have something to do with how powerful the light bulb is.

Checking an Appliance

If you have been able to bring in a small appliance, give it to some students and ask if they can find any electrical information written on it. Ask them to read what they find aloud. Note the significant numbers and units on the board, such as:

115 volts   1.5 amps (or amperes)   170 watts

Point out that the word watts is here again, with two additions — volts, and amperes.

Explain that people often use the nickname "amps" to mean amperes, and you may hear or see it either way. Amps and amperes mean the same thing.

Almost everything in our house that uses electricity will have on it information about volts, amperes, and watts.

Put on the overhead transparency of the rating plates. Go through the plates one by one, asking a student to read the volts, amperes, and watts, if all are given.

Homework Assignment

Pass out the worksheet and the checklist. Go over the assignment with the students. Suggest that they use the time remaining in the period to list on their worksheets the names of some appliances they know they have at home, so that they will have a head start when they get home.

Point out to the students that some plates may only give amperes (or amps) and not watts; and others may give only watts and not amperes. Just copy down whatever is on the rating plate.

Point out that we will not be filling in the last two columns this week, but we will later. Therefore, these worksheets should be carefully preserved for later use. You may wish to collect and save them for this purpose, although a question of privacy arises if you do. It is probably best to tell the students explicitly that you will not collect the sheets and that they do not have to share them with other students. Of course, you will discourage any who-owns-the-most contests.

If some parents will not permit their children to complete these worksheets, ask those students to go to a small appliance store and copy information from the appliances on sale.

Collect the checklists at the end of the period; they can be reused.

MODEL	TYPE & SERIAL	AMPS
3760	A 18685021	8.0
		VOLTS 120 AC
		HERTZ 25-60

UL **THE WONDER COMPANY**
East Oshkosh, Wisconsin 65342

Panavisic Color TV
Model CT-911V AC 120V 60 Hz 180 W
Product complies with D HEW rules 21 CFR part 278 applicable at date of manufacture.
Honisuma Electric Industrial Co., Ltd.
Osaka, Japan MG 413

Jones Crown Corp.

Covered by one or more of the following US patents: 3,181,861; 3,584,317; 3,823,754; 4,581,448; 4,601,217; 5,707,321; 5,723,968. Double Insulated. When servicing, use only identical replacement parts. Grounding not required.
Printed in USA

Electric typewriter
Model 9E
Volts 117 AC
Hz: 60
Amps 1.0
Watts 60

523654 REV C

Farmerware®
Model No. 264
120 volts 1600 watts 50-60 HZ A C
Made in USA
Farmerware
Division of MCA
Brooklyn, NY 17001
UL listed
toaster
342A

Name:

Measuring Electricity **Worksheet**

Examine all the appliances you can find in your home (ignore lights). Look for the nameplate on the appliance, which may list volts and amperes, and watts the appliance consumes. Some appliances may be so big you can't move them to find the plate; don't worry about that. Leave blanks where there is no information on the appliance. Put these sheets in a safe place and save them for later in the year.

Name of Appliance	Volts	Amps	Watts	Hours per year	Kilowatt-hours per year

A Checklist of Appliances

Most people don't realize how many appliances they have. To help you make your own record of the appliances in your home accurate, here is a list of some common and not so common appliances.

Kitchen

refrigerator
freezer
dishwasher
electric range
electric mixer
toaster
coffee maker
waffle iron
electric oven
microwave oven
blender
Crock-pot®
hot-dog cooker
hamburger maker
deep-fat fryer
electric knife
electric can opener
electric clock
trash compactor
garbage disposal
egg cooker
electric frying pan
electric yogurt maker
electric ice cream maker
popcorn maker
food processor
electric crepes maker
electric coal starter
rotisserie
toaster oven
oven vent fan

Bathroom

electric shaver
electric toothbrush
hair dryer/hair blower
hair curler
tooth irrigator
manicure machine
electric facial machine
electric shave-cream heater
portable electric heaters

Hobby

sewing machine
electric drill
electric saw
slide projector
movie projector
tape recorder
calculator
CB radio
electric exercise machine

Living Area

television set
phonograph or stereo
radio
computer games
toys
air conditioner
fan
electric bug-killer
ion generator
burglar alarm
smoke detector

Bedroom

electric heating pad
electric blanket
sun lamp
electric bed

Utility Room, Basement

vacuum cleaner
electric broom
washing machine
dryer
iron
electric water heater
humidifier
oil burner
fans
door bell
electric hedge clipper
heat pump
central air conditioner

Outdoor

electric barbecue
swimming pool heater
sauna
garage-door opener

Annual Energy Requirements of Electric Household Appliances

	Average Wattage	Estimated kWh Consumed Annually
Food Preparation		
blender	300	1
broiler	1,140	85
carving knife	92	8
coffee maker	894	106
deep fryer	1,448	83
dishwasher	1,201	363
egg cooker	516	14
frying pan	1,196	100
hot plate	1,200	90
mixer	127	2
oven, microwave (only)	1,450	190
range		
with oven	12,200	1,175
with self-cleaning oven	12,200	1,205
roaster	1,333	60
sandwich grill	1,161	33
toaster	1,146	39
trash compactor	400	50
waffle iron	1,200	20
waste dispenser	445	7
Food Preservation		
freezer (15-21 cu. ft.)		
chest-type, manual defrost upright-type	—	1,320
manual defrost	—	1,320
automatic defrost	—	1,985
refrigerators/freezers		
manual defrost 10-15 cu. ft.	—	700
automatic defrost, 16-18 cu. ft.	—	1,795
automatic defrost, 20 cu. ft. and up	—	1,895
Laundry		
clothes dryer	4,856	993
iron (hand)	1,100	60
washing machine (automatic)	512	103
washing machine (nonautomatic)	286	76

	Average Wattage	Estimated kWh Consumed Annually
water heater	2,475	4,219
water heater (quick recovery)	4,474	4,811
Comfort Conditioning		
air cleaner	50	216
air-conditioning (room)	860	860*
bed covering	177	147
dehumidifier	257	377
fan (attic)	370	291
fan (circulating)	88	43
fan (rollaway)	171	138
fan (window)	200	170
heater (portable)	1,322	176
heating pad	65	10
humidifier	177	163
Health and Beauty		
germicidal lamp	20	141
hair dryer	381	14
heat lamp (infrared)	250	13
shaver	15	0.5
sun lamp	279	16
tooth brush	1.1	1.0
vibrator	40	2
Home Entertainment		
radio	71	86
radio/record player	109	109
television		
black & white		
tube-type	100	220
solid-state	45	100
color		
tube-type	240	528
solid-state	145	320
Housewares		
clock	2	17
floor polisher	305	15
sewing machine	75	11
vacuum cleaner	630	46

The estimated annual kilowatt-hour consumption of the electric appliances listed is based on normal usage. When using these figures for projections, such factors as the size of the specific appliance, the geographical area of use, and individual usage should be taken into consideration. Note that the wattages are not additive since all units are normally not in operation at the same time.

*Based on 1000 hours of operation per year. This figure will vary widely depending on area and specific size of unit. See EEI-Pub #76-2 "Air Conditioning Usage Study" for an estimate for your location.

Source: EEI-pub #75-61, Edison Electric Institute, 90 Park Avenue, New York, N.Y. 10016.

Amperes, Volts, Watts

Objectives

This lesson contributes to students' understanding of the following concepts:

Amperes measure electric current: the more electrons that pass by in a given amount of time, the stronger the current.

Watts measure power: the rate at which energy is being used.

Voltage is a measure of electric potential.

Watts = Volts x Amps.

Format of the Lesson

Discuss completed worksheets

Amperes

Defining amperes (optional)

Amperes in the home

The watt

The difference between power and energy

Measuring power

The volt

Some practical applications: wires and fuses

How heavy a wire?

Assigning homework

Materials Needed

worksheets from previous day, completed by students.

chalkboard

fuses preferably including some which are burnt out.

circuit breaker not the little Mini-breaker replacements for screw-in fuses, but the black plastic, panel-mounting type used in new home construction. Ask an electrician to save you the defective ones when she replaces them.

Looking at the Worksheets

Ask students to examine the worksheets assigned in the previous lesson.

On the blackboard, put the headings from the worksheet:

Volts Amps Watts

Ask a student to give data for one of her appliances. Enter it on the chart.

Ask how many different voltages students found. All will range around 110 and 120 volts. Suggest to the students that, since these don't seem to vary much, we ignore voltage for the moment and go on to amperes. We will come back to volts, later.

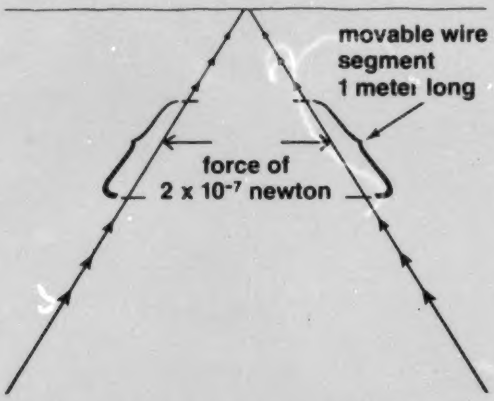
Amperes

What is electricity as we use it in our homes? By the seventh grade, most students will know electricity as a flow of electrons in a wire; if not, describe it to them as a flow of charges. These charges are almost always electrons. What can we measure or count in order to describe some electrons moving down a wire? (In most classes, some student will suggest counting the electrons.)

One quality of a flow of electrons that we could describe in numbers is how many electrons go by in a certain amount of time. That would measure the strength of the current. And that is what an ampere is used to measure, the strength of the current. One ampere represents a current that would carry about 6,242,000,000, 000,000,000 (six quintillion, two hundred forty-two quadrillion, or 6.242×10^{18}) electrons past any point on the wire in one second. Amperes describe the current flowing in the wire.

Amperes: How They're Defined (Optional!)

In actual practice, counting electrons is hard, so the definition of the ampere is framed in a different way. If you take two parallel wires with a current flowing through them, the wires will attract each other. The strength of this attraction, which can be measured, depends on the strength of the electric current. So the ampere is defined in terms of this attraction, not in terms of a number of electrons. One ampere is the constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular sections, and placed one meter apart in a vacuum, will produce between these conductors a force equal to 2×10^{-7} newton per meter of length.


movable wire segment 1 meter long
force of 2×10^{-7} newton

The Ampere in the Home

Let's look at our appliances. Ask if anyone found an appliance that drew less than an ampere. Enter the volts, amps, and watts of a few such appliances on the board. Were any appliances found that drew more than 10 amperes? List the data for some of those.

Which of these appliances do you think use a great deal of energy: (name some low amperage ones and some high amperage ones from the list on the board). (ANS: The ones with high amperage ratings.)

Tell the students that is correct, and the real way we can tell is by the figures in the last column, the watts.

The Watt

Which uses more energy, a 40-watt light bulb or a 100-watt light bulb? (ANS: The 100-watt bulb.) Watts are a measure of power, which is the rate at which energy is used.

The Difference Between Power and Energy

Let's think about the difference between measuring power and measuring energy. Suppose you heat a liter of water. You might heat it in three hours over a candle, or you might use a powerful torch and heat it to exactly the same temperature in 25 seconds. The amount of energy supplied is the same in both cases, but the torch was more powerful than the candle. It supplied more energy per minute.

Or suppose we want to lift a heavy weight. We could take a little tiny electric motor and, by using a lot of gears or pulleys, we could lift the weight. It might take hours. Or we could use an enormous electric motor that could lift the weight in a few seconds. The same amount of energy is needed to lift the same weight the same distance, but the big motor supplied the energy faster. It is more powerful.

Because power is not the same thing as energy, different units are needed to describe power. A unit that measures power must refer to time; it must tell us how fast energy is being supplied or used.

Measuring Power

The watt is named after James Watt. Does anyone know who James Watt was? (ANS: The person who perfected the steam engine.) James Watt didn't know much, if anything, about electricity, but he was very interested in power, because that was what he was trying to get his engines to produce. To try to find a unit to describe the power of his engines, James Watt measured the power of horses and invented a new unit. Can you guess what he called it? (ANS: Horsepower.) We still use horsepower in describing automobile engines and such things. Like horsepower, the watt is defined in terms of how massive a thing you can move how fast, and not in terms of electricity. One watt is the power that will, in one second, move a mass of one kilogram through a distance of one meter with an acceleration of one meter per second. (Don't memorize this!) So we see we don't have to talk about electricity in defining the watt.

The Volt

Now let's go back to our table and see if we can figure out what volts means. Can you see any relation between the numbers on the table?

Bring out that multiplying the first two columns, volts and amps, gives the last column, watts.

volts x amps = watts

Why do the electrons flow in the wire at all? They do so because of a difference in electric potential. Electric potential is something like the potential objects have for falling. If an object is high, and there is a low place beneath, it can fall. The distance the object can fall tells us how much energy is available from its fall; the farther it falls, the harder it will hit. Voltage is the unit used to measure differences in electrical potential.

If there's a very big difference in potential between two points, as there is between cloud and ground in a lightning storm, an electric current will flow between the points even though air is the conductor. High voltages are dangerous because they represent very large electrical potentials: it's like an object that's very high and has a long way to fall. On the other hand, you can put your hand across the terminals of a 1½-volt battery and you won't get shocked. Your skin is a good enough insulator to block the flow of current.

The volt is defined in terms of amperes and watts. One volt is the difference in electric potential between two points in a conductor through which a current of one ampere is flowing when one watt of power is dissipated between those two points.

You now know the three fundamental units for measuring a flow of electricity:

the volt

the watt

the ampere, or amps, for short.

Some Practical Applications: Wires and Fuses

Show the class a foot of 12-gauge, solid copper wire, such as is used to wire houses (and have handy some other lengths of wire of other gauges — perhaps a piece of magnet wire, some Litz wire, whatever). Ask the students whether they think any number of electrons you might want could go by in one second through the wire. How about this wire? It turns out that it can't. As you increase the amperage, the wire gets hotter and hotter until, finally, it melts. To keep that from happening in our homes, where it could lead to a fire, we use fuses or circuit breakers.

Pass around some fuses and perhaps a circuit breaker. Ask the students to locate the amperage markings on the fuses and circuit breaker. (In addition to the printed amperage, the amperage is also usually stamped on the central contact in the fuse's base.) Suggest they look through the little glass window in the front of the fuse and try to find a flat wire inside. This wire is made so that it will melt before your household wiring does. Compare the good fuses with the one that is burnt out.

If a fuse is marked 15 amperes, as household fuses usually are, and a current of more than 15 amperes flows through the fuse for any length of time, the fuse will melt and stop the flow of electricity.

How can we find out how many amperes we're using? Just add up the amperage of all the appliances plugged into the circuit. If they total more than 15, the 15-amp fuse will blow (or the 15-amp circuit breaker will trip).

When a fuse blows or a circuit breaker trips, find the cause of the problem before replacing the fuse or resetting the circuit breaker.

To reset a circuit breaker, push the lever all the way to OFF, then push it to ON.

Never bypass fuses; you could lose your home and maybe your life.

How Heavy a Wire?

Let's see something else we can learn from volts, amps, and watts. As we found out from the nameplates on the appliances, the voltage in our homes is about 117 volts. Does anyone know what the voltage of the electrical system in a car is? (ANS: 12 volts; though cars more than 10 years old may have 6-volt systems.)

Let's see what difference that makes in the wiring. Suppose we have a 100-watt light bulb. To power that light bulb in a 117-volt system, you will need .85 amps.

117 volts x **.85 amps** = 100 watts

But in the 12-volt system, you will need 8.3 amps.

12 volts x **8.3 amps** = 100 watts

To carry 8.3 amps you will need a much bigger wire than you need to carry .85 amps. In fact, if our households ran on 12-volt electricity and we used our existing wiring, we could only plug in 180 watts before the fuses blew.

12 volts x **15 amps** = 180 watts

Why do you think electrical transmission lines are operated at voltages in the hundred of thousands?

Homework Assignment

Pass out the worksheets, **Finding Watts** and **Finding Volts**.

Projects for Independent Investigation

1. Prepare a report to the class on the controversy between Thomas Edison and George Westinghouse on whether electricity should be distributed as AC (alternating current) or DC (direct current). Whose point of view prevailed? Why?
2. Build a current balance.

Finding Amperes

In most homes, each branch circuit has a fuse for either 15 amperes or 20 amperes. (New buildings use a circuit breaker instead of a fuse.) What amperage fuse is used where you live? __________ amps.

In these problems we will figure out the amperage when we know the volts (115 volts) and the watts. You may use a calculator if you like.

Example: How many amps does a 40-watt light bulb use?

$$\text{amperes} = \frac{\text{watts}}{\text{volts}}$$

$$\text{amperes} = \frac{40\ \text{watts}}{115\ \text{volts}}$$

amperes = .35 amperes

1. How many amperes does a 1400-watt hair dryer use?

$$\text{amperes} = \frac{1400\ \text{watts}}{115\ \text{volts}}$$

amperes = ______________ amperes

2. How many amperes does a 3-watt electric toothbrush use?

$$\text{amperes} = \frac{3\ \text{watts}}{115\ \text{volts}}$$

amperes = ______________ amperes

3. How many of the hair dryers could you run on a 20-amp circuit? _______ hair dryers.

4. How many of the toothbrushes could you run on a 20-amp circuit? _______ toothbrushes.

5. Millie is at home, trying to get ready to go out after a hard day at the office. Plugged into the same branch circuit are a reading lamp with a 60-watt bulb, a 400-watt television set, a 200-watt foot massager, and a hair dryer. The circuit has a 15-amp fuse; the volt is 115 amps. On its low-heat setting, the hair dryer uses 400 watts, and on high it uses 1100. If Millie turns the hair dryer to high, will the 60-watt light bulb go out? _________.

6. Take your appliance sheet and, for appliances for which you only had watts, calculate the amperes and enter them on the sheet.

Finding Watts

Solve these problems. If you have a calculator, you can use it. In all the problems, we are talking about 115-volt house current.

watts = volts x amperes

Example:

A toy uses two (2) amperes. How many watts will it draw?

watts = (115 volts) times (2 amperes)

watts = 230 watts

1. An electric iron draws 8 amperes. How many watts is it?

   watts = (115 volts) times (______ amperes)

   watts = ______ watts

2. A dishwasher uses 13.5 amperes. How many watts does it use?

   watts = (115 volts) times (______ amperes)

   watts = ______ watts

3. A fan is marked 3 amperes. How many watts is it? ______ watts.

4. A typical 19" solid state color television set draws 1.7 amperes.

   How many watts is that? ______ watts.

5. Take your appliance sheet and fill in the missing watts.

Meter Reading

Objectives

This lesson contributes to the students' understanding of the following concepts:

Energy must be measured to be bought and sold.

We consume energy at different rates at different times.

As a result of this lesson, students will be able to read the typical watt-hour meter. This skill requires the following understandings:

The dials of the meter read from left to right, like the digits in the numeral representing the reading.

Some of the dials read counterclockwise and some read clockwise.

When a pointer is between numerals, the reading is the lesser of the two numerals.

When a pointer seems to be exactly on a number, look at the dial to the right. If the pointer on that dial is between 0 and 1, it has passed zero and the reading on the dial to the left is the numeral the pointer seems to be on. If the pointer on the dial to the right is between 9 and 0, it has not reached zero yet and the reading for the dial to the left should be one less than the numeral it seems to be on.

Some readings must be multiplied by 10 or 100, as indicated on the meter face.

(Do not ask students to memorize these rules.)

Format of the Lesson

Discuss need for measuring in trade

Relate to trade in energy in the household

The watt and watt-hour

The kilowatt-hour

Meter-reading worksheet

Begin data collection for consumption patterns lesson

Materials Needed

worksheet **Meter Reading**, one per student.

worksheet **Electric Diary: One Day**, one per student.

worksheet **Electric Diary: One Week**, one per student.

Buying and Selling Energy

Discuss the importance of measurement in trade.

Ask what kinds of energy our families buy.

Summarize that, to buy this energy, we must be able to measure it.

What Units Are Used to Buy And Sell Electrical Energy?

Establish that a unit of measurement is needed to buy and sell electrical energy.

Review the electrical units we have learned: the volt, the ampere, and the watt.

Watts measures the amount of power an appliance (such as a light bulb) consumes. To find how much energy is consumed, we have to know how long the appliance was on. The greater the wattage of a light bulb, the faster it consumes energy. The longer it is on, the more energy it consumes.

So, we can define a unit of electrical energy. One watt-hour is the amount of electrical energy that would be consumed in one hour if we were using it at a rate of one watt.

Put the following equation on the chalkboard.

watts x hours = watt-hours

If we burn a 40-watt light bulb for two hours, how many watt-hours have we used? (ANS: 80 watt-hours.)

We can also have watt-seconds, or watt-minutes. But all these are too small to be useful in ordinary life, so we use an even bigger unit, the kilowatt-hour.

What does the prefix "kilo" mean? (ANS: 1000.) What is a kilometer? A kilogram?

The Kilowatt-Hour

How much electrical energy does a kilowatt-hour represent?

A 1000-watt light bulb burning for one hour.

A 1-watt light bulb burning for 1000 hours.

A 100-watt light bulb burning for how many hours? (ANS: 10 hours.)

A 50-watt light bulb burning for how many hours? (ANS: 20 hours.)

So there are many different ways of using up a kilowatt-hour.

Measuring Kilowatt-hours

Some device is needed to measure the kilowatt-hours we buy from the electric company. What is that device? (ANS: The electric meter.)

Tell the class that they will learn how (or, perhaps, review how) to read the electric meter. Pass out the worksheets. We suggest these be completed in class while your help is available.

Energy Consumption

When you are satisfied that most of the students can read a meter, pass out the other two worksheets. Both provide practice in meter-reading; the "week" is easier to do than the "day." Try to avoid getting all Saturdays for the day sheet, since Saturday is not a typical weekday. You may wish to have some students read the school's meter.

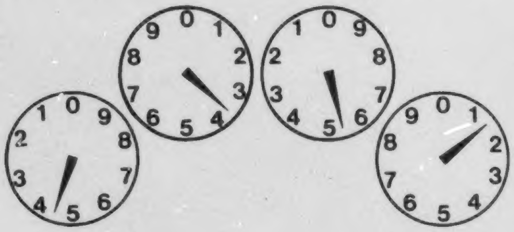
Be aware of the importance of protecting privacy when using these sheets.

Later in the unit, students will study their sheets to discover patterns in their use of energy.

Name:

Meter Reading

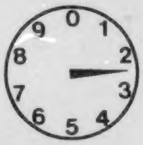
This exercise is for people whose utility meters look like this:

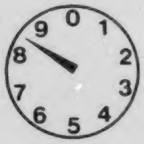


In this exercise, you will learn how to read your meter.

1. Each dial of the meter has a little hand. Usually the hand is between two numbers. Then the hand is indicating the number which is less, just like a clock.

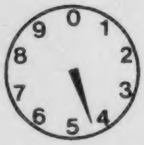
Here's a dial indicating the number 2.

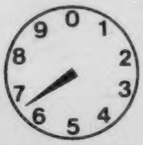




What is the reading on this dial? ________

What is the reading on this dial? ________

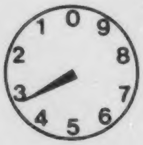




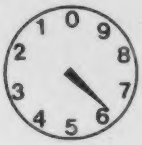
What is the reading on this dial? ________

2. Your meter will have a row of four or perhaps five dials. Look at the meter face at the top of the page. On the dial on the far right, the numbers go around just as they do on a clock. But look at the dial next to it. The numbers go around in the opposite direction. It reads counterclockwise. Whether the numbers go clockwise or counterclockwise, always read the smaller of the two numbers the hand is between.

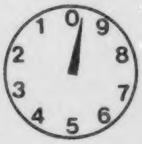
Here are some more dials.
What does this one read? ________


1 0 9
2 8
3 7
4 5 6

What is the reading on this dial? ________


1 0 9
2 8
3 7
4 5 6

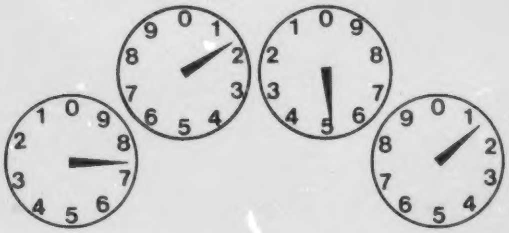
What is the reading on this dial? ________


1 0 9
2 8
3 7
4 5 6

3. The dials are arranged left to right in the same order as the digits in the number. Write down the numbers in order from left to right.

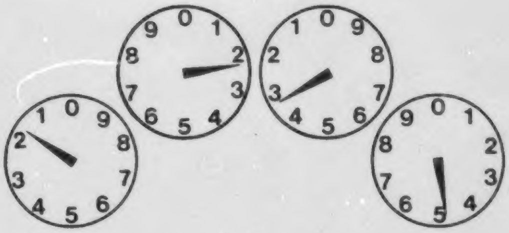
What does this meter read?

______ ______ ______ ______


1 0 9 2 8 3 7 4 5 6
9 0 1 8 2 7 3 6 5 4
1 0 9 2 8 3 7 4 5 6
9 0 1 8 2 7 3 6 5 4

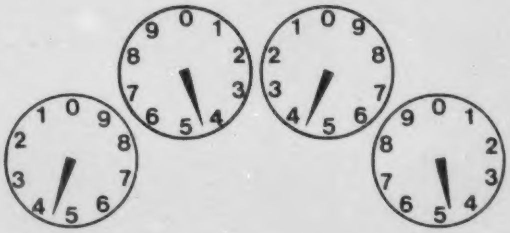
What does this meter read?

______ ______ ______ ______


1 0 9 2 8 3 7 4 5 6
9 0 1 8 2 7 3 6 5 4
1 0 9 2 8 3 7 4 5 6
9 0 1 8 2 7 3 6 5 4

What does this meter read?

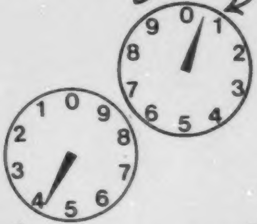
______ ______ ______ ______


1 0 9 2 8 3 7 4 5 6
9 0 1 8 2 7 3 6 5 4
1 0 9 2 8 3 7 4 5 6
9 0 1 8 2 7 3 6 5 4

4. Sometimes a hand seems to be pointing exactly at a number. Has it reached it yet or not? To find out, look at the dial to the right. If the hand on the dial to the right has already passed zero, then you should put down the number the other hand seems to be pointing at. If it hasn't, put down the next lower number.

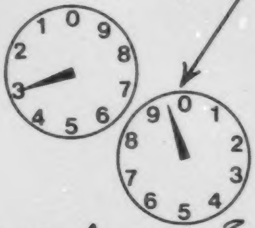
has just passed zero!

What do these two dials read? _____ _____


0 9 8 7 6 5 4 3 2 1
0 1 2 3 4 5 6 7 8 9

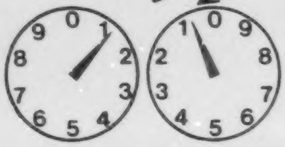
has not reached zero yet.

What do these two dials read? _____ _____

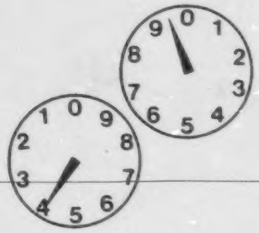

0 9 8 7 6 5 4 3 2 1
0 1 2 3 4 5 6 7 8 9

has this passed zero?

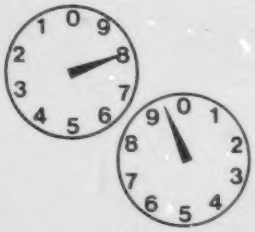
What do these two dials read? _____ _____


0 1 2 3 4 5 6 7 8 9
0 9 8 7 6 5 4 3 2 1

What do these two dials read? _____ _____

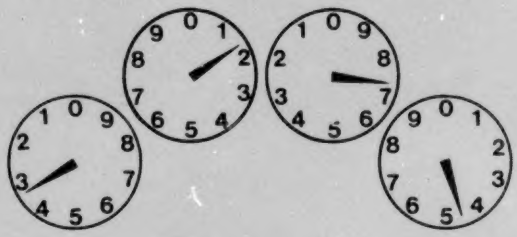

0 1 2 3 4 5 6 7 8 9
0 9 8 7 6 5 4 3 2 1

What do these two dials read? _____ _____

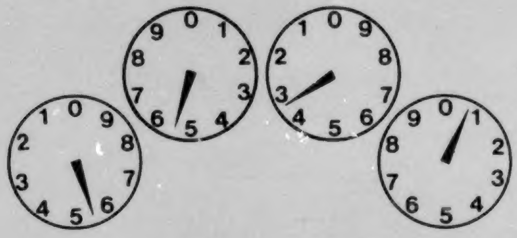

0 9 8 7 6 5 4 3 2 1
0 1 2 3 4 5 6 7 8 9

5. In some areas, utilities may have different rules for reading the last dial. The meter-person may be instructed to put down whichever number the hand is closest to, or the highest of the two numbers the hand is between. What is the rule in your area?

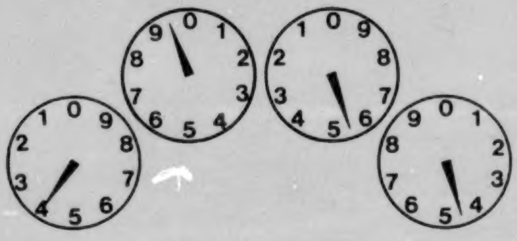
6. Now we're ready to read meters. Read the following meters:



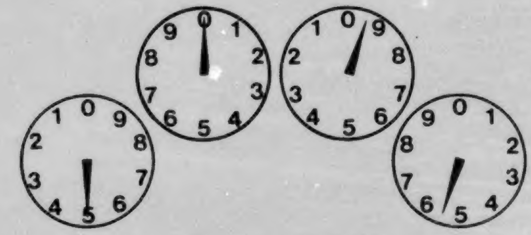
____ ____ ____ ____



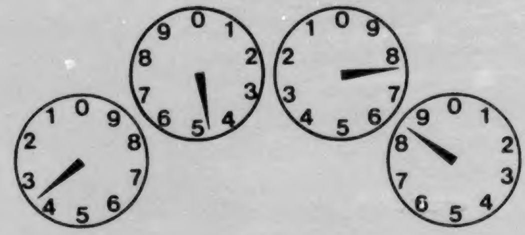
____ ____ ____ ____



____ ____ ____ ____

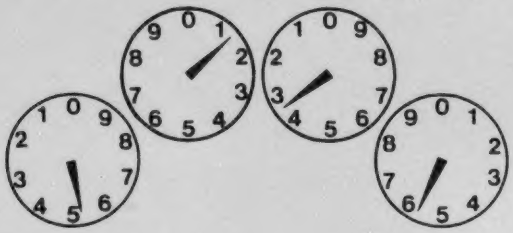


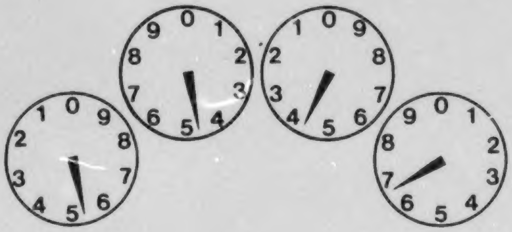
____ ____ ____ ____



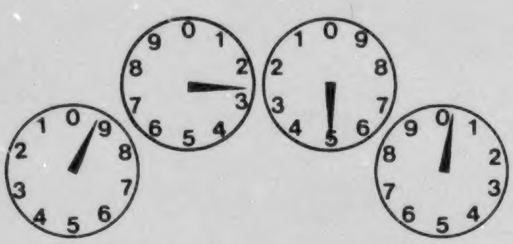
____ ____ ____ ____

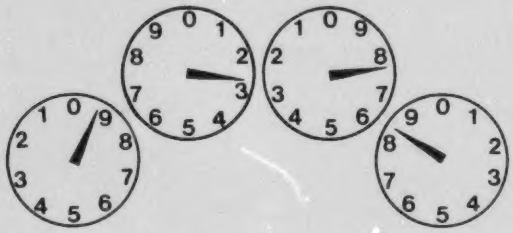
7. To find out how much energy we've used since the last time the meter was read, we have to subtract the old reading from the new reading. How much electricity did these houses use?



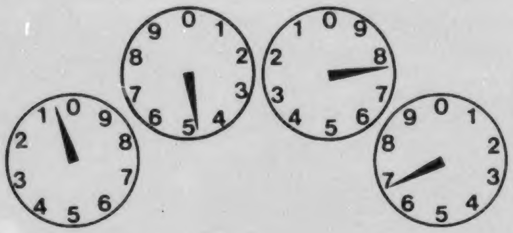


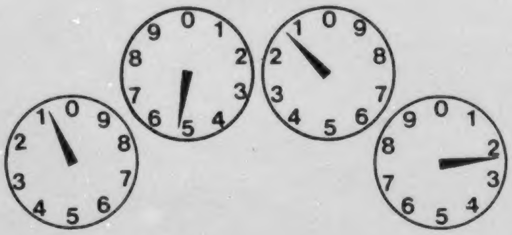
January 1 ___ ___ ___ ___ February 1 ___ ___ ___ ___ ______kWh





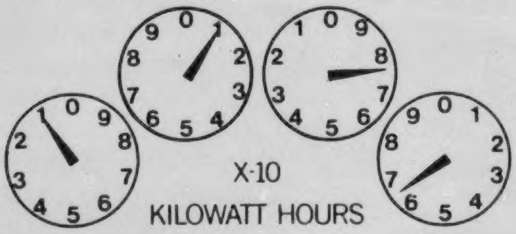
June 30 ___ ___ ___ ___ July 30 ___ ___ ___ ___ ______kWh





September 13 ___ ___ ___ ___ October 13 ___ ___ ___ ___ ______kWh

8. Some meters are marked "X-10" or "K-10." This means that, instead of reading kilowatt-hours, the meter reads tens (or twenties) of kilowatt-hours. If your meter has such a marking, you must multiply the reading by 10 (or, if the meter is marked "K-20," multiply by 20).



___ ___ ___ ___

Name:

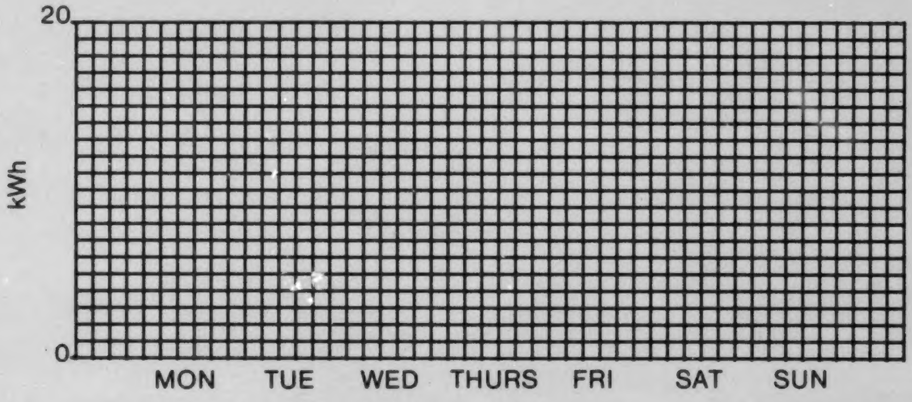
Electric Diary: One Week

During one week, every day, at the same time of day, read your family's electric meter. Of course, if you wanted to measure exactly by days, you would have to read the meter at midnight. But a good practical time to read it is before going to school or after dinner.

Date I began: ____________________

Day of Week	Time of Reading	Reading	kWh Used in Last 24 Hours
(Sunday)			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			
Sunday			

Use this form to make a bar graph of your weekly electrical consumption.



Do you notice any bumps? What caused them?

Save this sheet. In a different season, do the activity again and see if your pattern of consumption has changed.

Name:

Electric Diary: One Day

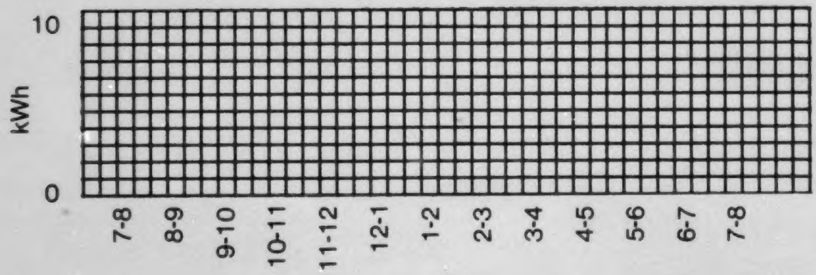
Choose one day, and read your electric meter every hour on the hour. Record your readings below. (If your meter does not have a dial that counts individual kilowatt-hours, you may not be able to complete this worksheet.)

Day of the Week: ______________________________

	Readings
7 AM	
8 AM	
9 AM	
10 AM	
11 AM	
Noon	
1 PM	
2 PM	
3 PM	
4 PM	
5 PM	
6 PM	
7 PM	
8 PM	

	Consumption
7-8	
8-9	
9-10	
10-11	
11-Noon	
Noon-1	
1-2	
2-3	
3-4	
4-5	
5-6	
6-7	
7-8	

Use this form to make a bar graph of your electrical consumption that day.



Save this sheet. On a different day of the week, or in a different season, do the activity again and see if your pattern of consumption has changed.

Notes

Reading Utility Bills

Objectives

The object of this lesson is to develop the students' ability to extract information from bills for electricity and natural gas of the type used in their community.

Format of the Lesson

Discuss buying energy at home

Discuss measuring electric power

Show transparency of electric bill and discuss features

Complete electricity worksheet

Discuss measuring the energy in gas

Pass out gas-meter worksheet

Show transparency of gas bill and discuss features

Pass out gas-bill worksheet

Materials Needed

chalkboard

utility bills if you cannot find people willing to donate their old bills for students' scrutiny, call the utility company educational representative and ask the company to send you sample bills. If that fails, photocopy a bill, paint out the name and numbers with a product like Liquid Paper, and insert new, plausible figures.

overhead transparencies of electric and gas utility bills.

worksheets one per student. The sheets referring to bills are provided only as samples. the forms used in your community will probably differ from those shown, and may not include all the information asked for.

Reading an Electric Bill

Reading a Gas Meter

Reading a Gas Bill

What Does It Cost to Take a Warm Bath? (optional)

Gas Diary: One Week

Teacher Background

Utility bills are not standardized across the United States, and some bills may not include all the items on the bills described in this lesson plan. Some may contain additional information. It is important that you study bills used in your locality prior to the lesson, so that you know what information they provide and exactly where on the bill it can be found. Almost all utilities will provide interpretive literature about their bills on request.

Buying Energy at Home

Ask the class what forms of energy their families buy. List these on the board. They may include gasoline, food and, in some areas, coal or propane, electricity, and natural gas.

Ask them how we know how much we have bought. Bring out that we must have a unit of measure and a way of measuring.

Measuring Electric Power

Ask the class what units can be used to measure electrical energy. (ANS: Watt-hours, or kilowatt-hours.)

In fact, that is how we buy our electricity, by the kilowatt-hour.

Ask students to describe when and how we pay for our purchases of electricity.

Discuss Electric Bill

Show an overhead transparency of a local electric bill (not the same one you have reproduced for the worksheet). Go over the various entries on the bill, asking students what they mean. Most are rather straightforward and will provide a chance for everybody in the class to contribute.

Some, however, are not so obvious. These might include:

The rate schedule. Discuss why different customers may pay different prices per kilowatt-hour. (In the past, big users always paid less. Now they sometimes pay more, so be careful about making generalizations.) Discuss how rates are set. It is helpful to have a copy of the rate schedules available for students to look at. These can be obtained from your public utilities commission.

Lifeline rates are a device used in some states to provide a basic amount of energy to all households at a lower than usual cost.

To avoid having to read the meter each month, yet have monthly billing, bills in some areas are based on *estimates*, which are corrected when the meter is read. In that case, the bill will have a code to show if it is based on a reading or on an estimate.

Pass out the worksheet on the electric bill. You may wish students to complete it as homework, or you may want to do this in class and save the discussion of the gas bill for the following class. In many classes, an entire period will have been consumed by this point.

Discuss Measuring the Energy in Natural Gas

We buy gasoline by the gallon, and electricity by the kilowatt-hour. What units do you think the gas company uses to measure the gas it sells?

List responses on the chalkboard. One way is to measure the volume of the gas.

[If some of your students seem a bit hazy on the concept of volume, you may wish to go through the following review:

Ask the class to name a unit we use to measure *length*. Someone will mention feet, or a foot. Apply the foot measurement to some real object, like the classroom: it is about so many feet long, and so many feet wide. Now suppose, instead of length, we wanted to measure *area* (to put new flooring in the classroom, for example). What unit would we use then?

Students will volunteer "square feet." Do a rough calculation of the area of the classroom floor, using the estimates of length and width already made.

Now ask what units we could use to measure the *volume* of air in the room. If students do not suggest "cubic feet," supply the term and then discuss what a cube is. Calculate the number of cubic feet of air in the classroom.]

Measuring the Gas We Buy

Homes and apartments using gas will have a gas meter. The school itself may have a gas meter that the class could visit. What would we expect the gas meter to measure? (ANS: Cubic feet of gas.)

Tell the class that reading a gas meter is much like reading an electric meter, even through the faces look a little different. Pass out the worksheet, **Reading a Gas Meter**, and ask students to complete it as homework.

Only a very few gas utilities sell gas by the cubic foot. If yours does, proceed from this point directly to looking at a typical bill, preferably as an overhead transparency.

However, gas utilities who get gas from a number of different sources, or who have large differences in altitude in their service areas, cannot bill directly for cubic feet. The reasons should be discussed with the students.

1. Natural gas is a mixture of different substances. Some gases produce more heat than others when they burn, and so are worth more.

2. Gas reaching the burner at sea level will be more compressed than gas reaching a burner on a mountaintop. At sea level, you will get more gas molecules per cubic foot and so more heat per cubic foot.

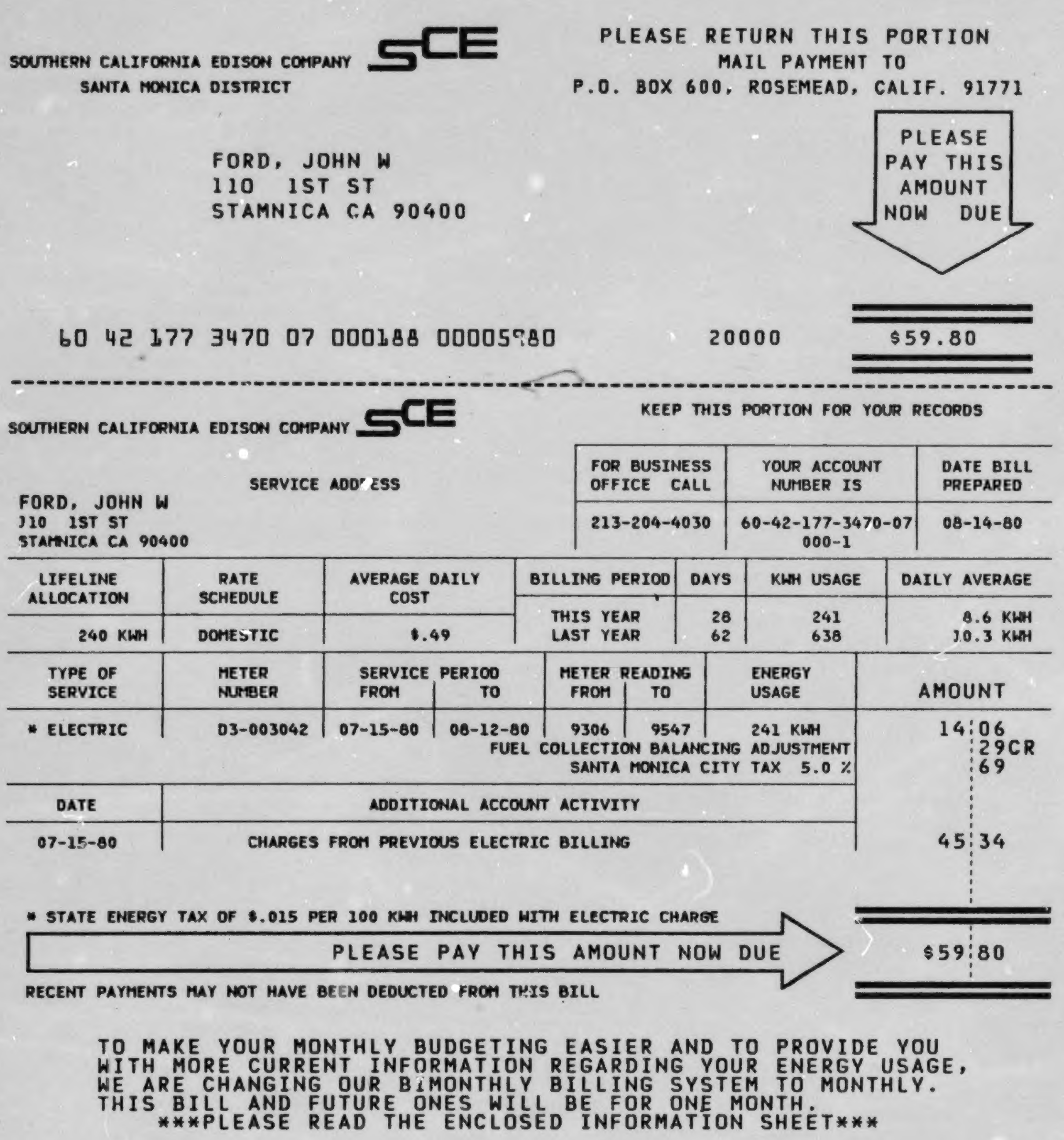
In order to pay for only the heat we are getting, we need to take into account how many molecules are in a cubic foot of the gas we get, and what kind of molecules they are.

To do this, the gas company uses a *billing factor*. The billing factor is a number used to convert cubic feet of the kind of gas you get at your home, at your altitude, to Btu's. Actually, gas companies don't use Btu's, but a unit called the *therm*, which is simply 100,000 Btu's. The billing factor is the number of therms that you could get burning 100 cubic feet of the gas delivered to you.

So the gas meter measures the number of cubic feet you've used, the gas bill tells you how many cubic feet that was, converts those cubic feet to therms, and then charges you for them according to your rate schedule.

Projects for Independent Investigation

1. Make a box representing a cubic foot.
2. Make a graph showing the daily consumption of electricity and gas in your school. Put it up in the hallway and update it every day.



SOUTHERN CALIFORNIA EDISON COMPANY SCE
SANTA MONICA DISTRICT

PLEASE RETURN THIS PORTION
MAIL PAYMENT TO
P.O. BOX 600, ROSEMEAD, CALIF. 91771

FORD, JOHN W
110 1ST ST
STAMNICA CA 90400

PLEASE PAY THIS AMOUNT NOW DUE

60 42 177 3470 07 000188 00005980 20000 $59.80

SOUTHERN CALIFORNIA EDISON COMPANY SCE

KEEP THIS PORTION FOR YOUR RECORDS

SERVICE ADDRESS
FORD, JOHN W
110 1ST ST
STAMNICA CA 90400

FOR BUSINESS OFFICE CALL	YOUR ACCOUNT NUMBER IS	DATE BILL PREPARED
213-204-4030	60-42-177-3470-07 000-1	08-14-80

LIFELINE ALLOCATION	RATE SCHEDULE	AVERAGE DAILY COST	BILLING PERIOD	DAYS	KWH USAGE	DAILY AVERAGE
240 KWH	DOMESTIC	$.49	THIS YEAR	28	241	8.6 KWH
			LAST YEAR	62	638	10.3 KWH

TYPE OF SERVICE	METER NUMBER	SERVICE PERIOD FROM	SERVICE PERIOD TO	METER READING FROM	METER READING TO	ENERGY USAGE	AMOUNT
* ELECTRIC	D3-003042	07-15-80	08-12-80	9306	9547	241 KWH	14.06
						FUEL COLLECTION BALANCING ADJUSTMENT	.29CR
						SANTA MONICA CITY TAX 5.0 %	.69

DATE	ADDITIONAL ACCOUNT ACTIVITY	AMOUNT
07-15-80	CHARGES FROM PREVIOUS ELECTRIC BILLING	45.34

* STATE ENERGY TAX OF $.015 PER 100 KWH INCLUDED WITH ELECTRIC CHARGE

PLEASE PAY THIS AMOUNT NOW DUE $59.80

RECENT PAYMENTS MAY NOT HAVE BEEN DEDUCTED FROM THIS BILL

TO MAKE YOUR MONTHLY BUDGETING EASIER AND TO PROVIDE YOU WITH MORE CURRENT INFORMATION REGARDING YOUR ENERGY USAGE, WE ARE CHANGING OUR BIMONTHLY BILLING SYSTEM TO MONTHLY. THIS BILL AND FUTURE ONES WILL BE FOR ONE MONTH.

PLEASE READ THE ENCLOSED INFORMATION SHEET

Reading an Electric Bill

1. Each of the company's electric meters is numbered. This is a bill for all the electricity that went through one particular meter. What was the number of that meter? ____________.

2. The electric company identifies this customer by an account number.

What is that number? ____________.

3. What was the date of the previous meter reading? ____________.

What was the reading on that date? ________ kilowatt-hours.

4. What was the date of this meter reading? ____________.

What was the reading? ________ kilowatt-hours.

5. How many days does this bill cover? ________ days.

6. How many kilowatt-hours have been used during that period? ________ kilowatt-hours.

7. How many kilowatt-hours did the customer use in this time period

last year? ________ kilowatt-hours.

Is the customer's consumption rising or falling? ________.

8. What number should the customer call if he has any questions about this bill?

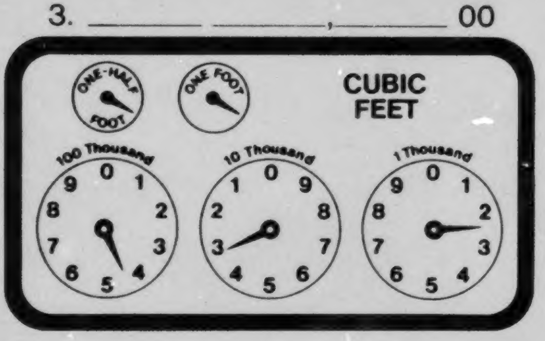
____________.

9. How much did the customer pay in taxes for the electricity? ____________.

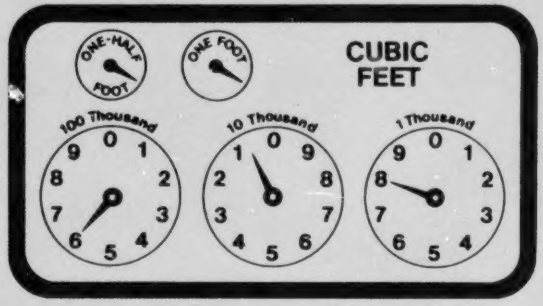
10. What rate schedule applied to this purchase? ________________________.

Now look at a bill for your own family and see if you can find the same information on it.

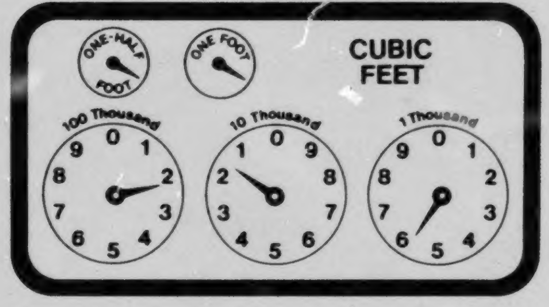
3. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

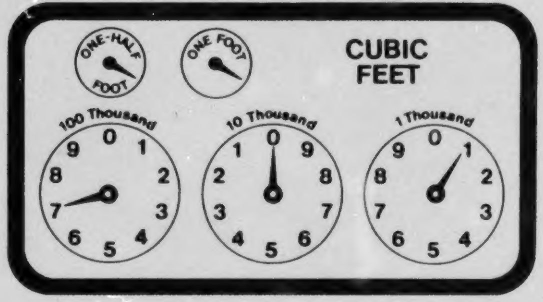
4. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

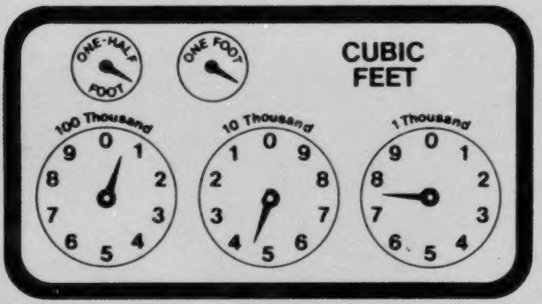
5. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

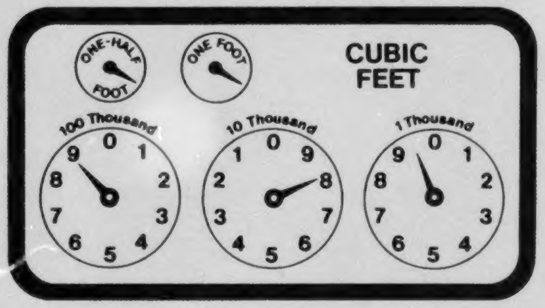
6. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

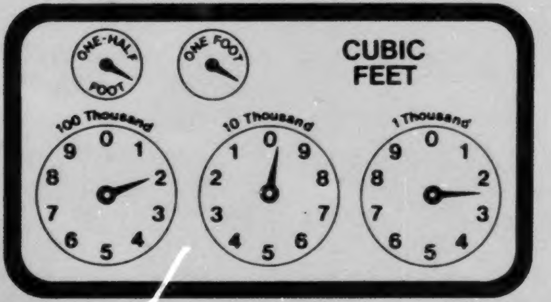
7. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

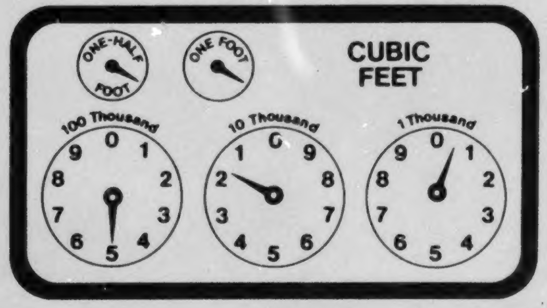
8. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

9. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

10. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

Reading a Gas Meter

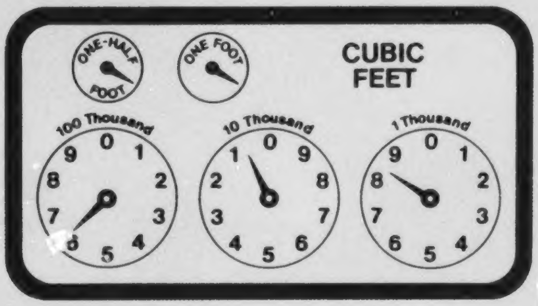
You will find it easy to learn how to read your gas meter, since you already know how to read an electric meter. The hands on the dials of the gas meter go around the same way as the hands on the electric meter, and follow the same rules:

If the hand is between two numbers, the reading is the lower of the two numbers.

The dials read from left to right, just like the numerals on a page.

If a hand seems to be exactly on a number, look at the dial to the right. If the hand on that dial is between 0 and 1, the reading is the number the hand is on. If the hand on the other dial is between 9 and 0, the reading is the next lower number.

Most gas meters look something like this:

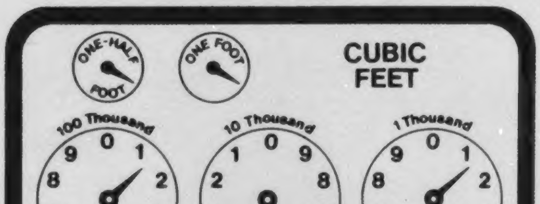

ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

On the top are two dials all by themselves. They are marked "one-half cubic foot" and "one cubic foot." The gas company uses these dials to check the meters, to make sure they are accurate. They are not used when you read the meter.

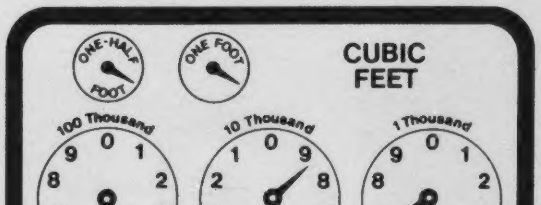
Notice that the dial on the far right is marked "1 Thousand." This means that each time the pointer on this dial goes around, a thousand cubic feet of natural gas has been used. The "5" on this dial therefore means 500 cubic feet. Because there are no hundred's or ten's dials, we must add two zeros to our reading to get the correct number of cubic feet.

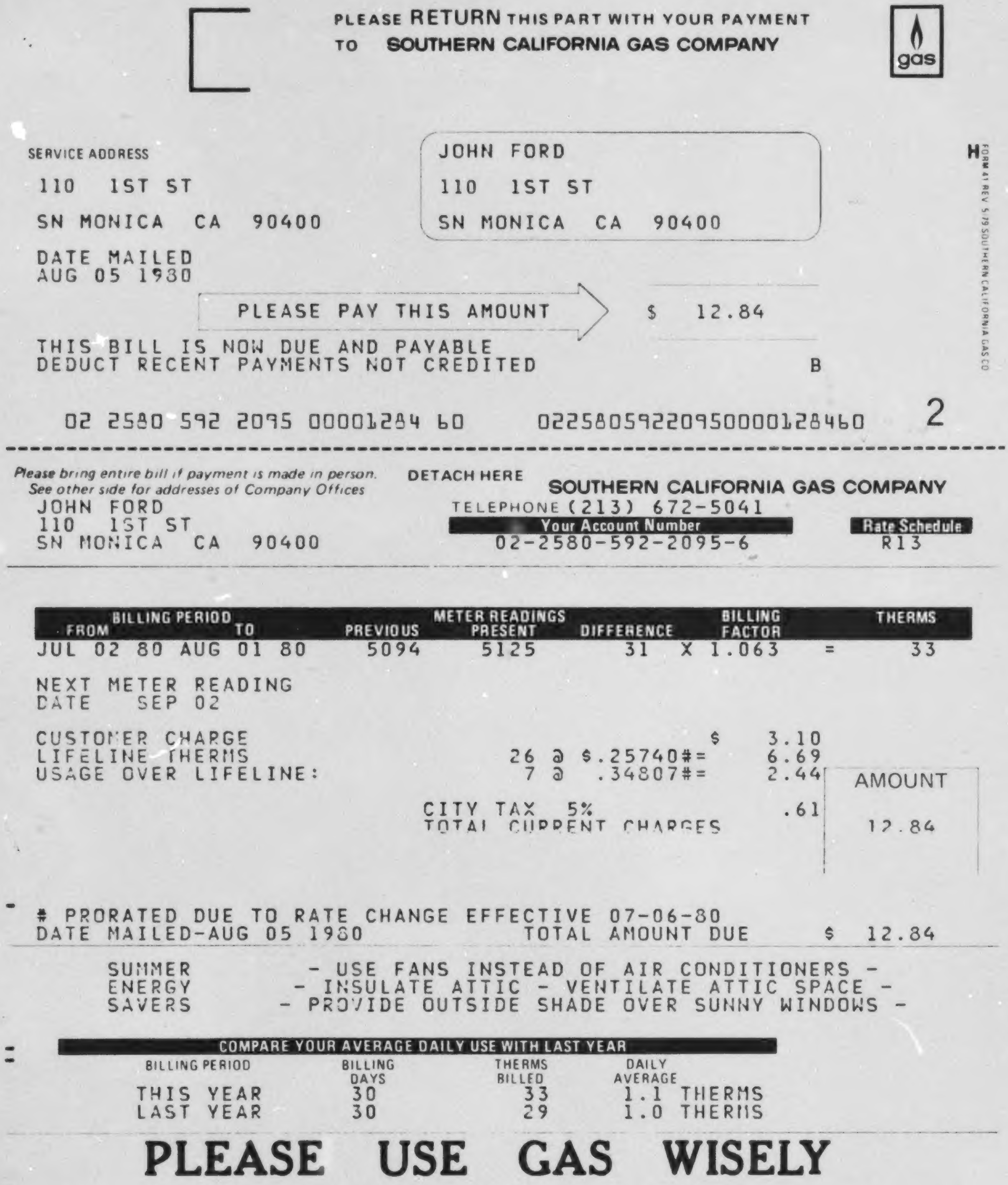
Here are some meters. Write down their readings in the blanks provided.

1. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand

2. ______ ______,______ 00


ONE-HALF FOOT
ONE FOOT
CUBIC FEET
100 Thousand
10 Thousand
1 Thousand



PLEASE **RETURN** THIS PART WITH YOUR PAYMENT
TO **SOUTHERN CALIFORNIA GAS COMPANY**

gas

SERVICE ADDRESS
110 1ST ST
SN MONICA CA 90400

JOHN FORD
110 1ST ST
SN MONICA CA 90400

H

FORM 41 REV 5/79 SOUTHERN CALIFORNIA GAS CO

DATE MAILED
AUG 05 1980

PLEASE PAY THIS AMOUNT $ 12.84

THIS BILL IS NOW DUE AND PAYABLE
DEDUCT RECENT PAYMENTS NOT CREDITED B

02 2580 592 2095 00001284 60 0225805922095000128460 2

DETACH HERE

Please bring entire bill if payment is made in person.
See other side for addresses of Company Offices

JOHN FORD
110 1ST ST
SN MONICA CA 90400

SOUTHERN CALIFORNIA GAS COMPANY
TELEPHONE (213) 672-5041

Your Account Number	Rate Schedule
02-2580-592-2095-6	R13

BILLING PERIOD FROM	TO	METER READINGS PREVIOUS	PRESENT	DIFFERENCE		BILLING FACTOR		THERMS
JUL 02 80	AUG 01 80	5094	5125	31	X	1.063	=	33

NEXT METER READING
DATE SEP 02

			AMOUNT
CUSTOMER CHARGE		$ 3.10	
LIFELINE THERMS	26 @ $.25740#=	6.69	
USAGE OVER LIFELINE:	7 @ .34807#=	2.44	
CITY TAX 5%		.61	
TOTAL CURRENT CHARGES			12.84

PRORATED DUE TO RATE CHANGE EFFECTIVE 07-06-80
DATE MAILED-AUG 05 1980 TOTAL AMOUNT DUE $ 12.84

SUMMER	- USE FANS INSTEAD OF AIR CONDITIONERS -
ENERGY	- INSULATE ATTIC - VENTILATE ATTIC SPACE -
SAVERS	- PROVIDE OUTSIDE SHADE OVER SUNNY WINDOWS -

COMPARE YOUR AVERAGE DAILY USE WITH LAST YEAR

BILLING PERIOD	BILLING DAYS	THERMS BILLED	DAILY AVERAGE
THIS YEAR	30	33	1.1 THERMS
LAST YEAR	30	29	1.0 THERMS

PLEASE USE GAS WISELY

Reading a Gas Bill

1. Every customer of the gas company has a different account number (in a big city, there are often people with similar names). What is this customer's account number?

______________________________.

2. What telephone number should they call if they have a question about their gas bill?

______________________________.

3. What was the date of the last meter reading? ______________________________.

4. What was the meter reading? ______________________________.

5. How many days have gone by between meter readings? ______________________ days.

6. How many cubic feet of gas have been used during the time between meter readings? (Remember that the numbers on the bills are *hundreds* of cubic feet.)

______________________ cubic feet.

7. Find the number used to convert the volume of gas metered to its heating value. What is it for this address? ________________________.

What is it called? ________________________.

8. How many therms did the customer use? ______________________ therms.

9. How many Btu's were obtainable from the gas this customer bought? (Remember 1 therm = 100,000 Btu.) ______________________ Btu's.

10. What did the customer pay for each of the first 26 therms? $______________________________.

11. What did the customer pay for each therm after 26? $______________________________.

12. How much were the taxes? $________________________.

13. How much does the customer owe in all? $______________________________.

14. Did the customer use more or less energy this year than last year? ______________________.

What percent of the customer's average daily consumption last year was the consumption this year? ______________________ %.

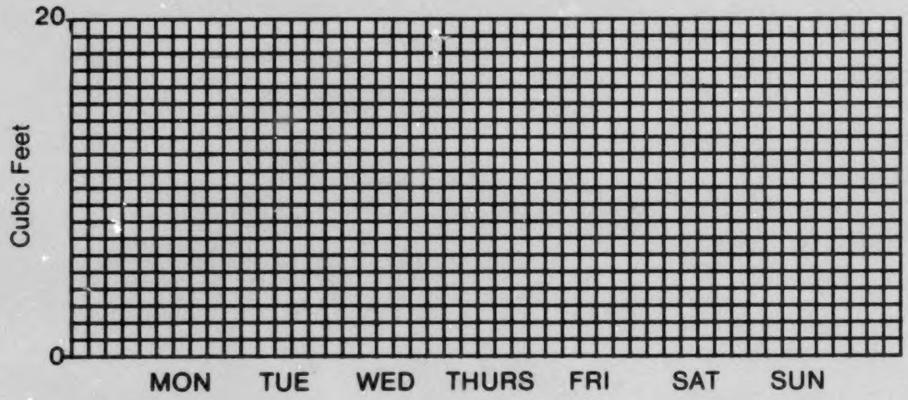
Gas Diary: One Week

During one week, every day, at the same time of day, read your family's gas meter. Of course, if you wanted to measure exactly by days, you would have to read the meter at midnight. But a good practical time to read it is before going to school or after dinner.

Date I began: ____________________

Day of Week	Time of Reading	Reading	Cubic Feet Used In Last 24 Hours
(Sunday)			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			
Sunday			

Use this form to make a bar graph of your weekly gas consumption.



Do you notice any bumps? What caused them?

Save this sheet. In a different season, do the activity again and see if your pattern of consumption has changed.

What Does It Cost to Take a Warm Bath?

In this exercise you will estimate how much it costs your family to heat the water for a bath. You are allowed to get help from other members of your family to do this activity. To do the activity, you need:

☐ a thermometer If your thermometer has only a Fahrenheit scale, convert to Celsius using the formula °C = 5/9(°F − 32).

☐ a gallon measure Make this by taking a one-gallon plastic jug and carefully pouring into it 16 cups of water, measured with a measuring cup. Mark the water level with a felt-tip pen.

1. How Much Heat Was Added to the Water?

First, we will figure out the number of calories put in the water.

Measure the number of gallons of water you use in a typical bath (all the water, not just the hot).

________ gallons. Convert gallons to milliliters by multiplying by 3,785.4. So you have

________________ milliliters of water in the tub.

One milliliter of water has a mass of one gram, so there are ____________ grams of water in the bathtub.

Measure the temperature of the water in the freshly drawn bath. ________ °C

Measure the temperature of the cold water (that's what's going into the water heater). − ________ °C

Subtracting, we get the rise in temperature in degrees ________ °C

calories = grams of water x rise in temperature in °C.

calories = ________________ grams x ________________ °C

= ________________ calories in the water.

2. How Much Energy Went into the Water Heater?

The water heater isn't perfect (who is?) so you have to put more energy into it than you get out as heat in water. The rest of the energy escapes into the room, up the chimney, and so forth. To estimate how much more energy you have to put in, multiply the calories in the water by these numbers:

Type of heater you use	**Factor**
electric	1.26
gas	2.17
fuel oil	2.27

Calculate the "calories-in."

(calories in water) x factor = ________________ calories into water heater

3. How Much Does the Energy That Went into the Heater Cost?

Choose the energy source that your family uses to heat hot water.

Gas. Gas is usually billed by therms. How much do you pay per therm? $_________. One therm is 100,000 Btu, or 251,995,760 calories. How many therms did you use to heat the water for a bath?

$$\frac{\text{calories into water heater}}{251{,}995{,}760} = \underline{\hspace{3cm}\text{therms}}$$

How much would that many therms cost? $_________. (If you are billed by the cubic foot, let one cubic foot equal 257,040 calories.)

OR

Electricity. How much do you pay for one kilowatt-hour? $_________. One kilowatt-hour is equivalent to 859,184 calories. How many kilowatt-hours would you need to get the calories you calculated went into the water heater?

$$\frac{\text{calories into water heater}}{859{,}184} = \underline{\hspace{3cm}\text{kilowatt-hours}}$$

How much would that many kilowatt-hours cost? $_________.

OR

Fuel Oil. How much do you pay for a gallon of fuel oil? $___________. One gallon of #2 heating oil yields 34,270,000 calories when burnt. How many gallons would you have to burn to get the calories you calculated went into the water heater?

$$\frac{\text{calories into the water heater}}{34{,}270{,}000} = \underline{\hspace{3cm}\text{gallons}}$$

How much would that many gallons cost? $___________.

(And, don't forget, you had to buy the water, too.)

Name:

Gas Diary: One Day

Choose one day, and read your gas meter every hour on the hour. Record your readings below.

Day of the Week: ______________________________

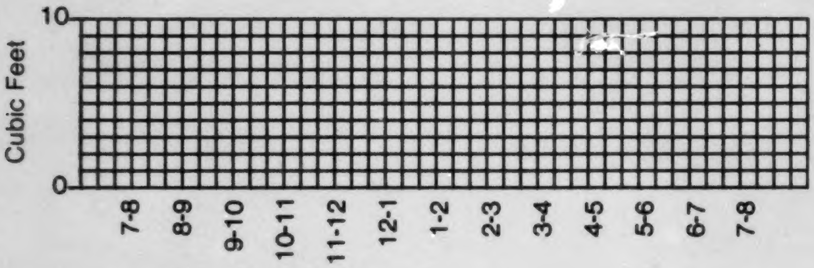
Readings

7 AM	
8 AM	
9 AM	
10 AM	
11 AM	
Noon	
1 PM	
2 PM	
3 PM	
4 PM	
5 PM	
6 PM	
7 PM	
8 PM	

Consumption

7-8	
8-9	
9-10	
10-11	
11-Noon	
Noon-1	
1-2	
2-3	
3-4	
4-5	
5-6	
6-7	
7-8	

Use this form to make a bar graph of your gas consumption that day.



Save this sheet. On a different day of the week, or in a different season, do the activity again and see if your pattern of consumption has changed.

Notes

Patterns of Energy Consumption

Note: This lesson involves data on home energy consumption. Before conducting the lesson, be certain that you have informed all parents that you do not require their children to reveal data on their families' use of energy to you or other students. See the remarks on **Protecting Privacy** in the introduction.

Objectives

In addition to its immediate objectives, this lesson initiates student collection of data on their own households' use of energy. This data will be used by the students in later activities in Units Six and Eight.

This lesson contributes to students' understanding of the following concepts:

Energy is measured when it is bought or sold.

There are regular patterns in our use of energy.

Different families tend to show similar patterns.

Format of the Lesson

Discussion of energy use during the day

Discuss electric-week worksheet

Discuss gas-week worksheet

Compare electric week and gas week

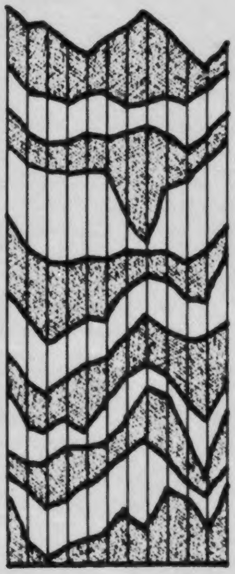
Discuss homework assignment

Materials Needed

completed worksheets from earlier lessons, **Electric Diary: One Day; Electric Diary: One Week; Gas Diary: One Week.**

worksheet **Electric Diary: One Year**. Notice that there is no vertical scale on this graph. This is deliberate, so that it will not be possible to read from the graph how much energy the family used, but only where the peaks and dips were and how steep they were.

Reproducing these worksheets using two papers of contrasting colors can result in a very dramatic display of the regularities of different families' energy consumption (without revealing anybody's consumption). After the students have completed their graphs, have them cut them out along the line representing consumption. Then glue the graphs down on a sheet of poster board, overlapping them like shingles, alternating colors, and lining up the month lines. The overlap should be as great as it can be without covering up any of the peaks and troughs of the graph above it. Similiar displays can be made for the day and the week, though you will have to devise your own forms.



worksheet **Gas Diary: One Year**. Treat in the same way as the Electric Diary above.

Preliminary Discussion

Do we use energy at about the same rate all around the clock, or do we use more at certain periods than others?

On the chalkboard, make a grid of the hours of the day similiar to that on the **Electric Diary: One Day** worksheet.

Ask the students to use their own worksheets and find the hour in which their families used the most electricity, and mark it 1.

Go through the hourly periods on the chalkboard and, by a show of hands, count the number of 1's for each hour and enter on the chalkboard.

What do we notice? That there is considerable clustering. If the one's occurred at random, we would expect them to be more or less spread out. But they aren't. Why? Discuss.

Now find the hour or hours in which you used half as much electricity as you did in the hour you marked 1. Mark that hour ½.

Do the ½'s cluster also?

Discuss what this means in terms of electric energy use. What are some of the implications? (We will take this topic up again in Unit Six.) You might tell this story.

In the early days of television, there was much less choice of programming than there is now. One evening comedy show was particularly popular and most of the people in New York City watched it. One effect of the show was to synchronize people's behavior. Many people waited until the commercial came on to use the bathroom. In those few minutes, then, water ran and toilets flushed all over the city. But the city sewage system was designed to handle a more or less constant flow of water from people flushing their toilets at random. The pipes were big enough to handle the needs of all the people, but not all at once. So the sewage system would back up into low-lying homes in the middle of that comedy show.

Another example is soldiers marching in step. When they come to a bridge, they break step. A bridge is built with many random steps in mind. All the feet coming down at once is a blow that could cause a bridge to collapse.

Examining Energy Use During a Week

Repeat the exercise with the week. Do we use more electricity on some days than others? Why? How do the causes of this pattern differ from the causes of the daily pattern? For example, are weekly patterns due more to custom, like Monday Wash?

Which is more bumpy, the day or the week?

Repeat the exercise with the gas week. Is it more bumpy or less bumpy than electricity usage? Why? Compare the uses of gas and electricity.

Assigning Homework

Pass out the worksheet, **Electric Diary: One Year.**

Observe that this is an activity which, unlike the earlier two, we cannot conveniently do by reading our meters. We have to rely on past records, namely, our utility bills. This means enlisting the cooperation of parents. Some people may not have saved their bills. In that case, many utilities will provide you with a record of your bills for the past year if you call and request it. Of course, a parent would have to do that.

Suggest to the class that the first step in doing this project is to talk to your parent or guardian and get their help. Show them the electric-week and electric-day work you have done; they may be very interested in finding out more about their use of energy; after all, they have to pay for it. As the year goes on, we investigate ways of lowering our energy bills. We can do this more accurately if we know when and what we use energy for.

Tell the class you realize that it may not be possible for everyone to do this exercise, and that a different project will be found for students who cannot obtain the necessary data. (Let this different project be an analysis of the school's use of energy over a year.)

Call the students' attention to the vertical axis of the graph. The space between each pair of horizontal lines represents 10 kilowatt-hours per month. We are not interested in how much electricity you used, but only in how your use of it changed. So you must number these lines yourself. Number the top line with a number in the tens just a bit more than the number of kilowatt-hours you used in the month in which you used the most electricity. Then go down the sheet, numbering all the lines by tens. Notice that the bottom line will NOT be zero.

Demonstrate how this is done on the chalkboard, using a worksheet with a prepared table of sample figures.

Name:

Electric Diary: Year

Dear Parents: As part of our energy-education activities, the students are trying to discover whether the amount of electricity a family uses changes from season to season. They can do this by looking at old utility bills, if you save them, but they will need your help in locating and, perhaps, in reading the bills.

Students record consumption on this sheet, but they do not have to bring it to class if you would prefer they didn't. I would like them to return the accompanying sheet, however, on which they try to locate peaks and dips. Thank you.

You could do this activity by keeping your own records, but it would take a year. So it is better to get this information by looking up old utility bills.

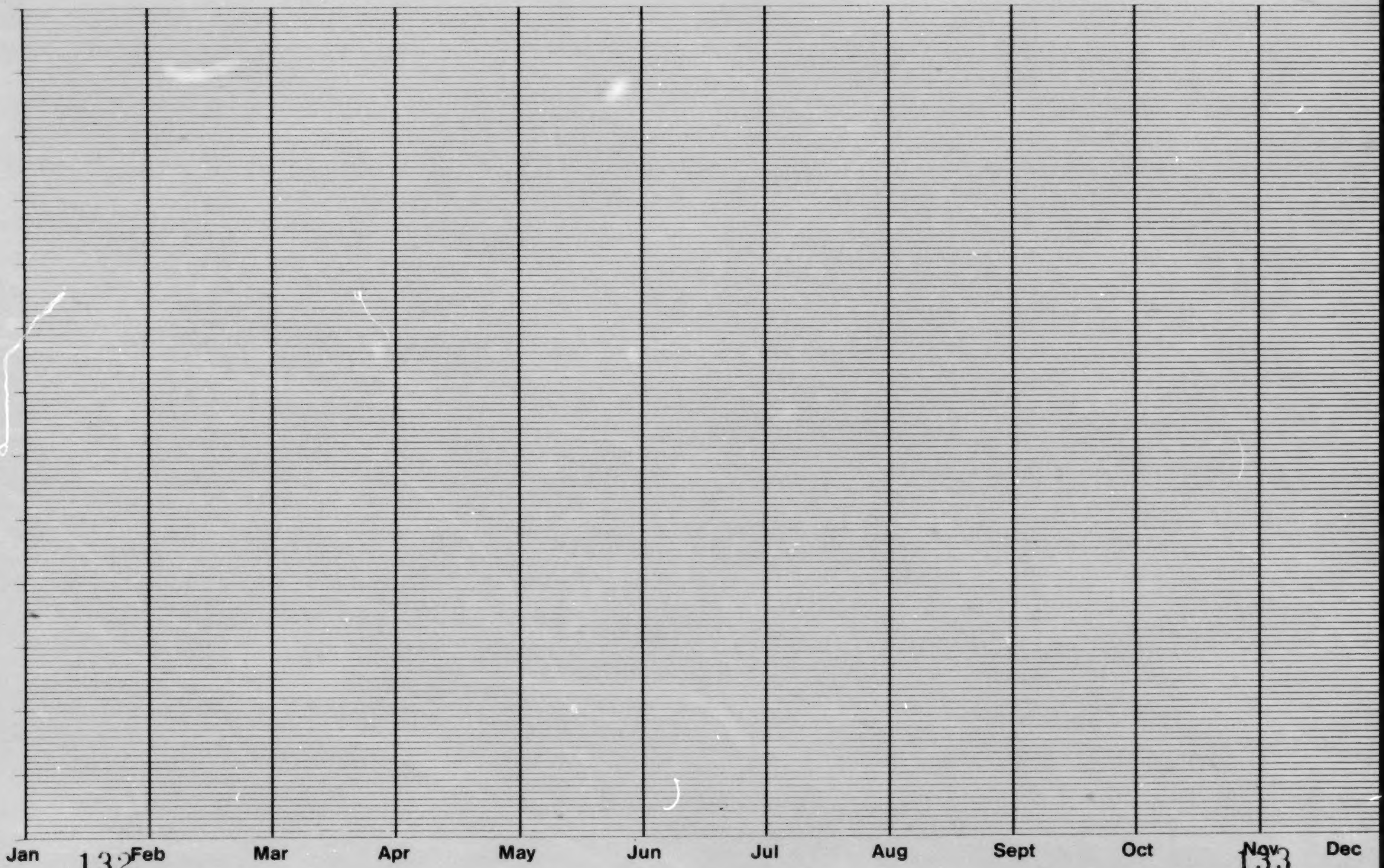
	1975	1976	1977	1978	1979	1980	Five-Year Average
January							
February							
March							
April							
May							
June							
July							
August							
September							
October							
November							
December							

Make a graph of either one particular year's monthly electricity consumption OR find the average monthly consumption over a period of several years and graph that. (Bimonthly if that is how your bills are issued.)

Begin by numbering the horizontal lines as you were shown in class. Number them in pencil. The space between lines represents 10 kilowatt-hours per month. Number the top line with a number ending in 0 which is just a bit bigger than the number of kilowatt-hours you used in the month in which you used the most. Then number the other lines moving down the page. The bottom line will not be zero, but it will be much less than the top line.

Make dots on each of the month lines at the point which represents your family's consumption of energy in that month. Make a heavy ink line through the dots. Then cut off the top part of the sheet, along the edge of the ink line. Finally, cut off the unlined scale with your pencil numbers.

The Shape of My Family's Consumption of Electricity Over a Year



Name:

Gas Diary: Year

Dear Parents: As part of our energy-education activities, the students are trying to discover whether the amount of gas a family uses changes from season to season. They can do this by looking at old utility bills, if you save them, but they will need your help in locating and, perhaps, in reading the bills.

Students record consumption on this sheet, but they do not have to bring it to class if you would prefer they didn't. I would like them to return the accompanying sheet, however, on which they try to locate peaks and dips. Thank you.

You could do this activity by keeping your own records, but it would take a year. So it is better to get this information by looking up old utility bills.

	1975	1976	1977	1978	1979	1980	Five-Year Average
January							
February							
March							
April							
May							
June							
July							
August							
September							
October							
November							
December							

Make a graph of either one particular year's monthly gas consumption OR find the average monthly consumption over a period of several years and graph that. (Bimonthly if that is how your bills are issued.)

Begin by numbering the horizontal lines as you were shown in class. Number them in pencil. The space between lines represents 10 terms. Number the top line with a number ending in 0 which is just a bit bigger than the number of terms you used in the month in which you used the most. Then number the other lines moving down the page. The bottom line will not be zero, but it will be much less than the top line.

Make dots on each of the month lines at the point which represents your family's consumption of energy in that month. Make a heavy ink line through the dots. Then cut off the top part of the sheet, along the edge of the ink line. Finally, cut off the unlined scale with your pencil numbers.

The Shape of My Family's Consumption of Gas Over a Year

Notes

How Many Calories Are There in a Watt-Hour?

Objectives

This lesson contributes to students' understanding of the following concepts:

Electricity can be converted to heat.

A measurement of electrical energy can be converted to a measurement of an equivalent amount of another form of energy.

Format of the Lesson

Discuss electricity to heat conversion

Conduct demonstration

Student calculations of conversion factor

Materials Needed

In this lesson we use electrical energy to heat water. There are several different ways of doing this, requiring different supplies. Before choosing one, read the discussion under Safety, below.

Option one:

electric calorimeter such as Fisher S41755 ($23.55).

Option two, our "homebrew" version:

Thermos® bottle preferably the "Super-Quart" size that holds 36 oz. and takes liner 14QF. About $7.00.

extension cord six-foot molded household. About $1.29.

lamp socket intermediate base, such as Leviton number 199, 59¢ in hardware stores.

bulb 40 watt intermediate base, 40T6½/2, made by Westinghouse and others for use in display cases. About $2.50 at hardware stores. The intermediate base is one step smaller than the household "medium" size and one size larger than the candelabra base. This size is small enough for the socket to get through the neck of the Thermos bottle. If you have many low voltage isolated outlets, you may wish to use a 12 volt bulb instead. See below.

silicone glue-sealer such as General Electric Catalog number GE2562-01DP. ($3.19 for 83mL, much more than you need). Available in hardware stores.

Option three, without the Thermos bottle:

immersion heater one-cup type

OR

aquarium heater preferably the type used with a separate thermostat, just a tube containing a heating element packed in sand.

Teacher Background

In this investigation, electricity is used to heat a measured mass of water, preferably in a Thermos bottle. Knowing the change in temperature of the water and its mass, we can calculate how many calories of energy (in the form of heat) were added to the water. Knowing the input of electrical energy in watts, and the time the heater was on, we can calculate how many watt-hours of energy (in the form of electricity) were added to the water. Of course, we are talking about the same energy (changing from one form to another), and so the measurements must be equivalent. Comparing them tells us how many calories is equivalent to a watt-hour.

Safety

Combining water and electricity obviously raises a question of safety.

One way of minimizing hazard is to use heaters designed for water, such as a one-cup immersion heater or an aquarium heater. Unfortunately, it is difficult to get good results with these because of the trouble it takes to insulate the water containers they will fit, and because they have a lot of thermal inertia themselves.

The homemade substitute, whose construction is described below, consists of a 40 watt waterproofed bulb run on line voltage. Note that there is **NO** exposed conductor anywhere in the finished setup if the plastic-walled Thermos specified is used. Still, we suggest that if this is the apparatus you choose, the investigation be done as a teacher demonstration.

A third alternative, if you have an isolated low voltage power supply, is to use a low voltage lamp such as a 12 volt automobile bulb. Since bayonet sockets are hard to find, you will probably have to solder wires directly to the bulb; otherwise, construction would resemble that described below. Incidentally, the demonstration does not work well with 110 volt 7½ watt bulbs, the size used for Christmas trees, and you would need an automotive bulb that drew around 40 watts as well.

Constructing the Heater

This should be done by an adult, not by students.

Cut the molded socket (not the plug!) from one end of the extension cord and throw it away. Strip about 1 cm of insulation from the two wires. Twist the strands of each wire together and bend the uninsulated portion of each into a U-shape.

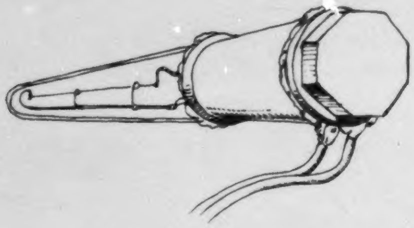
Unscrew the cap at the end of the socket. Two metal pins will be seen. Place one U over each pin. Be sure there are no loose strands of wire connecting the two pins. Screw the cap back on. (Ordinarily, these pins are used to penetrate the insulation of the wire. The wire used in household extension cords is not the right gauge or type for that system to work reliably.)

Clean all grease from the socket and the glass near the base of the light bulb. Screw the 40 watt light bulb into the socket, not too tightly. Plug in the assembly to confirm that the wires are making good contact with the pins.

Trim only the tip from the nozzle that comes with the silicone sealer, so that only a small hole shows. Put the nozzle on the tube. Pushing a bead of sealer **ahead** of the nozzle, squirt sealer into the space between the bulb and socket. Be generous. Do not pull the nozzle away from the sealer you've extruded; push towards it! Go all the way around the socket. Then unscrew the bulb one quarter turn and screw it back in again, fairly tight.

Squirt into the holes where wire is supposed to enter and leave the socket, as much as will go in. Be especially careful to go all around the wires. Then run a bead of sealer around the joint between the screw-on cap and the rest of the socket.

The entire construction, start to finish, takes about five minutes. Replace the cap on the sealer tube. Let the sealer dry for 24 hours, then test the bulb by immersing it in water in the Thermos and plugging it in. Always put the bulb in water before turning it on; dunking a hot bulb could shatter the glass.



Converting Electricity to Heat

Begin the lesson by discussing the following sequence of questions:

Do you know any way of converting electricity to heat?

Do you know a way of measuring a quantity of heat? (ANS: Description of ways of measuring calories or Btu's.)

Do you know a way of measuring a quantity of electrical energy? (ANS: Kilowatt-hours.)

If we can convert some energy in the form of electricity into the form of heat, then a measurement of the amount of energy in kilowatt-hours must be equivalent to a measurement of the same energy in calories. There must be a conversion factor to convert kilowatt-hours to calories, just as there is a conversion factor to convert inches to centimeters.

How can we find out how many calories there are in a kilowatt-hour?

Entertain proposals from the class.

Demonstration

You may want to give students the activity sheet to help them follow the demonstration; in any case, provide the worksheet and let students do the calculations. (If you have the necessary equipment, you may want students to do the activity in groups.)

Post-Activity Discussion

The "correct" value for the number of calories in a watt-hour is 860.4. You may want to share this value with the class and discuss what the sources of inaccuracy in our experiment might be. For example, was water the only thing heated? (As a general rule, other substances, like glass and plastic, have specific heats very different from that of water.) Could energy escape from the Thermos? How accurate were our measurements? Could we design a more precise experiment?

Summarize for the class that, since energy is interchangeable from one form to another, any measurement is also interchangeable. We will do this as we learn ways of measuring other forms of energy.

Converting Electricity to Heat

You know that electrical energy can be converted to heat. Therefore, there must be a way of finding how many calories are equivalent to one watt-hour of electricity. In this investigation, you will try to do that.

To do this experiment, you will need:

☐ an all-plastic Thermos bottle

☐ a thermometer graduated in degrees Celsius

☐ a graduated cylinder or volumetric flask

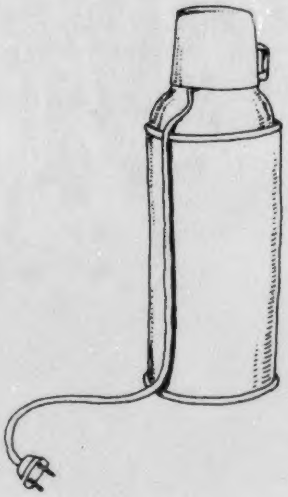
☐ a clock with a second hand or a digital stop watch

☐ an electrical power supply approved by your teacher

☐ a waterproofed low-voltage light bulb and socket, or electric heater, supplied by your teacher

voltmeter and ammeter; or multimeter (optional)

Do you have everything you need?



Procedure

Step One: Measure 800 milliliters of water and place it in the Thermos bottle. What is the mass of one milliliter of water? Make a record of the mass of the water you put in the bottle.

Step Two: Examine the light bulb and make a record of its marked wattage. Insert the light bulb into the Thermos. **DO NOT PLUG IT IN YET!** Be sure it is as far down in the bottle as possible, completely covered with water. Measure the temperature of the water and make a record of it.

Step Three: Put the cap on the bottle, gently force-fitting it (you won't be able to screw it on because of the wire). Put the cup over that.

Step Four: Connect the light bulb to the electrical supply and begin timing. Make a record of the time, to the nearest second, when you plugged the bulb in. Leave the bulb on for 15 minutes, to the nearest second.

Step Five: If you have an electric meter, measure and record the voltage and amperage of the current flowing into the bulb while the bulb is on.

Step Six: At the end of 15 minutes, unplug the bulb. Leave it in the water. Measure the temperature of the water and make a record of the reading.

Step Seven: Put away the materials.

Step Eight: Calculate a factor for converting watt-hours to calories. You may use the worksheet provided by your teacher.

How Many Calories in a Watt-Hour?

A. Calculate how much electrical energy went into the Thermos.

volts X amps = watts

watts X minutes = watt-minutes

_______________ volts

X _______________ amps

(If you did not use a meter, enter wattage of bulb here) _______________ watts

X _______________ 15 minutes

_______________ watt-minutes

Can you change that to watt-hours? _______________ watt-hours

B. Calculate the increase in heat energy in the Thermos.

(change in temperature in degrees Celsius) X (mass of water in grams) = calories

end temperature _______________ °C

beginning temperature – _______________ °C

change in temperature _______________ °C

volume of water = _______________ milliliters ≅ mass of water heated X _______________ grams

calories _______________ calories

C. Calculate the conversion factor.

So _______________ calories = _______________ watt-hours

or _______________ calories = 1 watt-hour

Some questions

1. Why did we use a Thermos bottle? _______________

2. Did we heat anything besides water? How will that affect our accuracy? _______________

Notes

Converting Energy Measurements

Objectives

This is an enrichment lesson for students who are not intimidated by word problems. The problems have been chosen with a view to building the students' perspective on the relative size of work, heat, and human energy. Some of the problems are deliberately bizarre, just for fun.

Format of the Lesson

Assignment

Materials Needed

worksheet **Brainteasers**.

Preliminary Discussion

Before passing out the worksheet, please be sure students understand that most of the problems ASSUME that all of one kind of energy gets changed to another. In reality, this is almost never true!

Answers

1. Consider just one kilogram of water.

force = mass x acceleration
force = 1 kg x 9.8 m/s/s

work in joules = (1 kg x 9.8 m/s/s) newtons x 980 meters

= 9604 joules
(and since 1 joule = 4.18 calories)
= 9604/4.18 calories
= 2297 calories, or enough to warm the 1000 grams of water about 2.3°C, to 22.3°C.

2. 37 watts for 8 hours = 296 watt-hours.

1 watt-hour = 860 calories
296 watt-hours = 254,560 calories

To raise 60 liters (= 60,000 gm) of water 30°C would require (60,000 x 30) 1,800,000 calories. So the answer is no.

3. 1 Calorie = 1000 calories
500 Calories = 500,000 calories

1 calorie = 0.000001161 kilowatt-hours
500,000 calories = 0.5805 kilowatt-hours
= 580.5 watt-hours

580.5 watt-hours divided by 100 watts = 5.8 hours (rounding off).

0.8 hours x 60 minutes = 48 minutes.

So the answer is 5.8 hours, or five hours and 48 minutes.

4. 0.00000000000003 Btu x 1,180,000,000,000,000,000,000,000 atoms
= 35,400,000,000 Btu.

The last two problems provide motivation for introducing the subject of exponential notation to able students.

5. 220 horsepower x 24 hours in the day = 5280 horsepower-hours.

1 Calorie = 0.00156 horsepower-hours (1000 times more than a calorie)
3000 Calories = 4.68 horsepower-hours

5280 horsepower-hours divided by 4.68 horsepower-hours = 1128.2 or, rounded off, 1128 people.

6. 1 Btu = 0.000293 kilowatt-hours.
32,000 Btu = 9.376 kilowatt-hours
= 9376 watt-hours

9,376 watt-hours divided by 100 watts per bulb = 93.76 bulbs or, rounded off, 94 100-watt bulbs.

7. 1 Btu = 0.000293 kilowatt-hours.
5000 Btu = 1.465 kilowatt-hours
= 1465 watt-hours

1465 watt-hours divided by 60 watts per bulb = 24.4 light bulbs. So 25 light bulbs would produce more heat than the air conditioner could remove.

8. 3000 Calories per day per person = (3000 divided by 24 hours per day) calories per hour per person.

= 125 Calories/hour/person
= 125,000 calories/hour/person

1 Btu = 252 calories.
5000 Btu per hour = 1,260,000 calories per hour.

1,260,000 calories per hour divided by 125,000 calories/hour/person = 10.08 persons.

So 11 people would provide more heat than the air conditioner could remove.

9. volts x amps = watts.

9 volts x 0.015 amp = 0.135 watts

Since the table does not give a conversion factor for watts, we will have to use a stratagem. Suppose the radio ran for an hour. It would consume 0.135 divided by 1000 kilowatt-hours, or 0.000135 kilowatt-hours.

1 kilowatt-hour = 1.341 horsepower-hours
0.000135 kilowatt-hours = 0.000181 horsepower-hours

To produce that many horsepower-hours in one hour, the radio must be 0.000181 horsepower. Using this amount of power, how long a ramp would be needed to lift a mass of one pound one foot?

10. Again, think about one hour.

1 kilowatt-hour = 1.341 horsepower-hours
1 watt-hour = 0.001341 horsepower-hours
37 watt-hours = 0.049617 horsepower-hours
= 0.05 horsepower-hours (rounding off to number of significant figures we started with).

The person who can put out 0.05 horse power-hours in one hour is a 0.05 horse power person.

Brainteasers

Some Conversion Factors

1 food Calorie = 1 kilocalorie = 1000 calories.

1 calorie = 0.000001161 kilowatt-hours = 0.00000156 horsepower-hours = 0.003968 Btu = 4.18 joules.

1 kilowatt-hour = 861,244 calories = 1.341 horsepower-hours = 3414 Btu = 3,600,000 joules.

1 Btu = 252 calories = 0.000293 kilowatt-hours = 1054 joules.

force = mass x acceleration

work = force x distance

watts = volts x amperes

In working these problems, assume that in every energy transformation all the energy that went in came out in the form we're measuring. This really almost never happens.

1. Angel Falls in Venezuela is the highest waterfall in the world. It is 980 meters high. The temperature of the water at the top is 20°C. The acceleration due to gravity is 9.8 meters per second per second. Suppose that, when the water hits the ground at the bottom of the waterfall, all its mechanical energy is transformed to thermal energy. What will the temperature of the water at the bottom of the waterfall be?

2. A person working an eight-hour day can put out about 37 watts of mechanical energy continuously. When he's done, he will want a bath. Was the energy he put out enough to raise the temperature of a bathtub containing 60 liters of water from 10°C to 40°C?

3. How long would a 100-watt light bulb run on the food energy in a 500-Calorie (food Calories!) chocolate sundae?

4. When a single atom of uranium 235 splits in a nuclear reactor, it gives of about 0.0000000000003 Btu. How many Btu's would you get out of a pound of uranium 235?
(There are about 1,180,000,000,000,000,000,000,000 atoms in a pound of U-235.)

5. The engine of a large automobile can put out about 220 horsepower continuously. If people run on 3000 Calories a day, how many people does it take to equal one large automobile?

6. How many 100-watt light bulbs would you need to provide the same heat in a room as a 32,000 Btu heater?

7. A typical small room air-conditioner can remove 5,000 Btu's per hour from the air in the room. How many 60-watt light bulbs could you turn on before you were putting more heat into the room than the air conditioner could remove (assuming the only heat coming into the room was from the light bulbs)?

8. Suppose a person uses up 3000 Calories a day, evenly spread through all 24 hours. (Do you think that's what really happens? Why not?) How many people could you put in the room with the 5000-Btu-per-hour air conditioner before the people were too much for the air conditioner?

9. A transistor radio draws 0.015 amps at nine volts. How many horsepower is it?

10. How many horsepower is the 37-watt person?

Conversion Factors for Some Common Units

(Those equivalences that define the unit being converted are indicated by an asterisk; all other conversion factors are approximations.)

Power

1 horsepower = 745.7 joules per second = 42,4356 Btu per minute = *550 foot-pounds per second = 745.7 watts

1 watt = *1 joule per second = 3.414 Btu per hour = 14.34 calories per minute = .001341 horsepower

Energy, Work, Quantity of Heat

1 Btu (British thermal unit) = 1055 joules = 252 calories = .00039 horsepower-hours = 777.6 foot-pounds = * the quantity of heat needed to raise the temperature of one pound of water one degree Fahrenheit at or near its point of maximum density (39.1°F)

1 calorie = 4.184 joules = .003968 Btu = * the amount of heat needed to raise the temperature of one gram of water, at 15°C, one degree Celsius

1 Calorie = 1 food calorie = 1 kilocalorie = 1 kilogram-calorie = 1000 calories = 1000 gram-calories

1 electron volt = 1.602×10^{-19} joules

1 erg (obsolete) = 1×10^{-7} joules = 9.48451×10^{-11} Btu = 2.39006×10^{-8} calories

1 foot-pound (obsolete) = 1.35582 joules = .001284 Btu = .324048 calories

1 joule = .0009485 Btu = .73756 foot-pounds = .000278 watt-hours = *1 newton-meter, the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force

1 horsepower-hour = 2,684,520 joules = 2546 Btu = 641,616 calories = .7457 kilowatt-hours

1 kilowatt-hour = 3,600,000 joules = 3410 Btu = 860,000 calories

1 therm = * 100,000 Btu (used on gas bills). Also, some people used to call a Btu a therm

1 quad = *1 quadrillion Btu = 1×10^{15} Btu

Miscellaneous

1 barrel (U.S.) of petroleum = 42 U.S. gallons

1 cord of wood occupies a pile 4 feet by 4 feet by 8 feet (128 cubic feet) and weighs about 1.25 tons. The actual volume of wood will be about 30 cubic feet.

1 langley = 1 calorie per square centimeter

1 langley per minute = 221 Btu per square foot per hour

How Big Is a Quad?

(One quad equals one quadrillion Btu (1,000,000,000,000,000 or 1 x 10^{15} Btu.)
(That equals 252,000,000,000,000,000 calories (small calories, not food Calories.)

To get a quad of energy, you would need:

40,000,000 tons of bituminous coal
50,000,000 tons of sub-bituminous coal
293,000,000,000 delivered kilowatt-hours of electricity
1 day's food energy for 720,000,000,000 laborers
105,000,000 tons of city garbage
62,500,000 tons of lignite
1,000,000,000,000 cubic feet of dry natural gas
172,400,000 barrels of oil
11,000,000,000 gallons of propane
62,500,000 tons of oven-dried wood
96,200,000 tons of green wood
28,571 pounds of U-235

The Laws of Thermodynamics (and Some Corollaries)

The First Law

Energy is conserved.

Energy is neither created nor destroyed.

The total amount of energy in the universe is constant.

Energy in equals energy out.

No perpetual motion machine of the first kind is possible.

There's no free lunch.

The Second Law

The entropy of the universe tends to a maximum. —*Clausius, 1865*

Any process whose **net** effect is the raising of a weight and the cooling of an object is impossible. —*Lord Kelvin*

No perpetual motion machine of the second kind is possible.

Any change, the net effect of which is to increase the order of the universe, is impossible.

You can't unscramble an egg.

If you think things are mixed up now, just wait. —*H.A. Bent, 1965*

Heat never flows from a cold body to a warm one.

The process of heat conduction cannot be completely reversed by any means. —*Max Planck*

Not only is lunch not free, there's a tax payable in heat.

Heat Content of Fuels

Liquids

	Btu per gallon	calories per liter
asphalt	158,000	10,520,000
aviation gasoline	120,200	8,003,000
butane	103,000	6,868,000
60% butane - 40% propane	98,330	6,549,000
distillate fuel oil	138,700	9,237,000
ethyl alcohol	100,000	6,658,000
jet fuel — kerosene type	135,000	8,988,000
hydrogen (liquid)	30,950	2,061,000
kerosene	125,000	8,989,000
methyl alcohol	70,000	4,661,000
gasoline	125,000	8,329,000
propane	91,330	6,081,000
residual fuel oil	149,700	9,967,000

Solids

	Btu per pound	calories per kilogram
anthracite coal	13,500	7,500,000
bituminous coal	13,800	7,667,000
lignite (dry)	11,000	6,111,000
peat (air-dry)	7,000	3,889,000
oven-dry maple	8,580	4,767,000
green maple	6,500	3,611,000
oven-dry Douglas fir	9,050	5,028,000
run-of-the-woodpile	6,000	3,333,000
feedlot manure (50% H_2O)	3,090	1,717,000
municipal waste	4,570	2,539,000
bagasse	4,830	2,683,000
rice hulls and straw	6,600	3,667,000

Gases

	Btu per cubic foot atmospheric pressure	calories per cubic meter
hydrogen	300	267
natural gas	1,019	907

First-Law Efficiency

Objectives

This lesson contributes to the students' understanding of the following concepts:

Energy can be measured.

Energy measurements can be converted from one type of unit to another.

When we use energy, we are usually unable to convert all the energy we put in into the form we want.

The ratio of the energy we get out in the form we want it, to the energy we put in, is called (first-law) efficiency.

In evaluating energy use, we must look at all parts of the system.

Format of the Lesson

Review energy use as converting one form to another

Review energy measurement and conversion factors

Idea of efficiency

Demonstration

Student calculations

Optional: comparison with second pot

Review demonstration system

Optional: Discuss variables

Optional: Discuss sources of error

Materials Needed

water

thermometer graduated in degrees Celsius.

graduated cylinder to measure cubic centimeters of water. If you have no graduated cylinder you may use an ordinary cup measure; one cup equals about 236.5 milliliters. Or jars can be calibrated to hold one liter, marking the level on tape on the side of the jar.

sauce pan or pot, about two-liter size. Ideally, the investigation should be done twice, once with a pot with a heavy flat bottom, like a Farberware pot, and once with a thin aluminum pot with a dinged and beaten up bottom.

electric hot plate you must know how many watts or amps this hot plate draws.

clock or watch with a sweep second hand.

activity sheet **How Efficient Is an Electric Hot Plate in Heating Water?** One is needed for each student actually doing the investigation. If it is done as a teacher demonstration, activity sheets are not necessary.

worksheet **Hot Plate Efficiency Calculations** One per student.

Using Energy Usually Involves Converting It from One Form to Another.

Discuss some household uses of energy in terms of energy flows. Ask such questions as,

"Tell me something you use energy for in your household."

"What kind of energy do you start with?"

"What kind of energy do you end up with?"

Establish that there is always an energy input and an energy output.

Review Measurement and Conversion

Point out that in all the examples the students have given they could measure the energy they started with. For example, they have learned how to measure electric energy.

Point out that they can also measure the energy that they got out in the form in which they wanted it. For example, we can measure heat energy, mechanical energy, and so forth.

Efficiency

We have a special name for the ratio

$\frac{\text{energy out}}{\text{energy in.}}$ We call it efficiency.

This ratio can be expressed as a percentage.

Discuss Demonstration

Propose that we do an investigation comparing the amount of energy we put in with the amount of energy we get out in the form we want. We will do this by using an electric hot plate* to heat some water.

"What kind of energy goes into an electric hot plate?" (ANS: Electricity.)

"How can you measure the amount of energy being used by a hot plate?" (ANS: Measure kWh consumed.)

"What form of energy are we trying to get?" (ANS: Heat in the water.)

"What units can we conveniently use to measure heat in the water?" (ANS: Btu's or calories.)

""Is it possible to convert the kilowatt-hours to calories?" (ANS: Yes, if we know the conversion factor.)

Ask students to make a wild guess at what the efficiency of the hot plate and pot will be.

Pass out the activity sheets, if students are to perform the investigation, and calculation work sheets.

Assign students to the following jobs:

Water Measurer

Time Measurer

Temperature Measurer

If you have more than one hot plate (and enough electricity to run them simultaneously) this investigation can be done by several groups of students. Comparing results (particularly if identical hot plates and pans are used) provides a valuable opportunity to discuss sources of experimental error.

If you have one hot plate and one pan and must do the investigation as a demonstration, have the students who are making the measurements write the figures they obtain on the chalkboard. The rest of the students may enter the data on their worksheets and calculate individually.

Directions for the investigation are given on the activity sheet.

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*Apparently the first to think of using the hot plate to demonstrate efficiency were Mark Terry and Paul Witt. Such an experiment is described in their excellent book, **Energy and Order, A High School Teaching Sequence** (San Francisco: Friends of the Earth, 1976).

Some Pitfalls

Heating 1 liter of water on a 1000 watt hot plate should take five to seven minutes.

Don't let the water boil. If the water actually comes to a boil, the calorie measurement will no longer be valid, since energy used in changing 100°C water to 100°C steam does not increase its temperature. (But a student might want to try determining how many calories it takes to convert 1 gram of 100° water to steam. No additional apparatus is needed.)

Instructions on the worksheet call for turning on the hot plate before putting the pot on it. This allows the hot plate to reach an equilibrium temperature with the room. An alternate procedure is to put the pan of water on the hot plate before turning it on. In that case part of the electrical energy going into the hot plate during the measured period is being used to heat the hot plate itself. The disadvantage of that procedure is that to replicate the experiment, you must let the hot plate cool to room temperature, and that takes a long time.

Experimenting with Different Pots

If time permits, it is very instructive to repeat the investigation using different pots, to see if efficiency differs from pot to pot. In fact, it will. To ensure that a striking difference will exist, use one pot with a strong, flat bottom, like a Farberware pot, and another with a dented and beaten up bottom, like a battered thin-gauge aluminum pot. The efficiency of the hot plate-pot system is very sensitive to the contact between the pot and heating element, and thin aluminum pots with dented bottoms conform very poorly to the surface of the electric hot plate.

To save time, start measuring water for the second pot as soon as the first pot is on the hot plate. Provide additional worksheets.

After the Investigation

Review, step by step, what has been done:

How did we measure the energy in?

How did we measure the energy out?

Did we get as much energy out as we put in?

What happened to the missing energy? Where did it go?

Is the percentage we arrived at the efficiency of the pot, or the efficiency of the hot plate? (This is easier to discuss if you've tested several pots.)

Would the pot have the same efficiency on a gas stove? (ANS: Try it and find out.)

What we have obtained is the efficiency of this particular pot-hot plate combination, or system; not the efficiency of the pot itself.

Variables (optional)

Many classes are capable of some very stimulating speculation on what the variables in this investigation are, especially if they have compared different pots. A good starter question is why the efficiency of the pots differed. Ask the class to devise an experiment to test each hypothesis proposed.

Although it is best if students suggest the variables, here are some leading questions. (You might think of more.) In all the following questions, by "does it matter," we mean, "Would you get different results if you repeated the experiment and changed only this factor?"

Does it matter how long we heat the pot?

Does it matter what temperature the water is to begin with?

Does it matter what the pot is made of?

Does it matter what shape the pot is?

A key concept in understanding the role of many of these variables is that the rate of heat flow between two bodies depends on the difference in their temperatures. Starting with water at 30°C will not give the same results as starting with 20°C water because the rate of heat flow from pot to room will be greater.

Sources of Error (optional)

Even if all variables are controlled, we would get a range of results. (This will have happened if you were able to do the investigation in groups with identical pans and hot plates, or repeated it.) Why does this happen?

What measurements go into our calculations?

How sure can we be of each of these measurements? Volume of water, for example. How many milliliters off do you think you might have been?

Temperature. With what accuracy can our thermometers be read? (Try it — have several students read the same pot of water and record their measurements separately.)

Time. How many seconds error might have been possible in reading the clock, or in putting on or taking off the pot?

How accurate is the wattage or amperage rating of the hot plate?

How does wattage depend on the line voltage? Is our line voltage what the manufacturer expected? Does it change?

How do these sources of error compound one another?

Homework Assignment

An optional homework assignment, which requires only kitchen utensils, is provided on the opposite page for possible reproduction.

The next lesson plan, **Systems Efficiency**, includes a worksheet which provides data on energy inputs and outputs from home water heaters, and reinforces the concept of efficiency by giving students practise in calculating efficiencies. If you don't plan to use that lesson, you may wish to use that worksheet as homework to conclude this lesson.

Projects for Independent Investigation

1. In which type of stove is the efficiency of heating water least sensitive to differences in pots: an electric stove, or a gas stove? Substantiate your opinion with experimental measurements.
2. What differences does a cover make in increasing the efficiency of a pot used to heat water?
3. Design an energy-efficient pot.
4. Who was Benjamin Thompson (Count Rumford)? Report to the class on Rumford's improvements in fireplaces. See if you can find his suggestions for improving stoves and pots.

Homework Assignment

In this experiment you will try to determine which is the most efficient pot for heating water on your home stove. The amount of water to be heated is exactly two cups.

1. Choose two pots you think might be the most efficient ones on one particular burner on your stove.
2. Put two cups of water in each of the two pots. Make sure the water is at the same temperature. If you think that the water that came out of the faucet first is warmer than the water that came out later, let the pots of water sit until they reach room temperature.
3. We will estimate how much energy is being used to heat the water by measuring the length of time the pot is on the stove. We will estimate temperature by removing the pot at the moment at which it begins to boil. Boiling is not the time at which small bubbles appear on the sides of the pot. By boiling we mean a full, rolling boil.
4. Turn on the gas or electric burner. Note the time and put one of the pots on the burner. As soon as it comes to a boil note the time and take if off. Immediately subtract to find how many seconds the pot was on the burner. Write the number in the space below. Now do the same thing with pot number two.

seconds for pot #1 to come to a boil

______________________ seconds.

seconds for pot #2 to come to a boil

______________________ seconds.

5. Was one pot more efficient than the other? Can you think of any reasons why?

Hot Plate Efficiency Calculations

1. Calculate the number of calories added to the water.

One calorie is the amount of energy needed to raise the temperature of one gram of water one degree Celsius.

calories = (rise in temperature in degrees Celsius) x (grams of water)

To find the rise in temperature:

ending temperature (in degrees Celsius) ________ °C
beginning temperature − ________ °C
rise in temperature ________ °C

To find the number of calories added to the water:

grams of water heated X ________ grams
calories added to water ________ calories

2. Calculate the number of calories supplied to the electric hot plate.

wattage of electric hot plate ________ watts
minutes pot was on hot plate X ________ minutes

watt-minutes = watts x minutes

energy delivered to hot plate ________ watt-minutes

Which has more energy,a watt-minute or a watt-hour?

Knowing there are 60 minutes in an hour, change the watt-minutes to watt-hours. ________ watt-hours
One watt-hour is equivalent to about 860.4 calories, X 860.4 ________
so the total energy input to the hot plate was ________ calories

3. Calculate the efficiency of your pot plus hot plate combination.

$$\frac{\text{energy out in desired form (hot water)}}{\text{energy in (as electricity)}} =$$

$$\frac{\_\_\_\_\_\_\ \text{calories}}{\text{calories}} \quad \text{X } 100\% = \_\_\_\_\_\_\ \%$$

How Efficient Is an Electric Hot Plate in Heating Water?

To find out, we would have to measure the energy input (the electricity supplied to the hot plate) and the energy output in the form we wanted (heat added to the water). Then we could compare the two. In this experiment, we will make these measurements and then see what part of the energy in came out the way we wanted it

Your teacher may assign one student to measure the mass of water, one to measure time, and one to measure temperature. Or you may be asked to do this experiment all by yourself.

To do the experiment, you need:

☐ an electric hot plate

☐ a pot

☐ a graduated cylinder or other means of measuring milliliters of water

☐ thermometer graduated in degrees Celsius

☐ watch or clock with a sweep second hand

Do you have all the things you need?

Procedure

Read all the directions before starting to do the experiment.

Step One: Examine the hot plate. How many watts is it? Make a note of the wattage. Turn on the hot plate and let it sit for two minutes while you get the pot ready. Allowing the hot plate to warm up lets it get as hot as it's going to. When the hot plate has just been turned on, most of the energy goes into warming up the hot plate itself.

Be sure the hot plate is in a safe location where people won't accidentally burn themselves.

Step Two: Measure some room-temperature water and put it in the pan. Fill the pan more than half full. Make a note of how many milliliters of water you put in the pot.

Do you remember that one milliliter of water has a mass of one gram? How many grams of water are in the pot?

Step Three: Measure the temperature of the water in the pot, in degrees Celsius. Make a note of the temperature. It should be room temperature.

Step Four: Decide on a time when you will put the pot on the hot plate. Make a note of the time (say, ten thirty-one and twenty seconds). At exactly that time, put the pot on the hot plate.

Now decide on a time when you will take the pot off. Let it be a whole number of minutes. If you used a liter of water, five minutes is a good length of time. So if you put the pot on at ten thirty-one and twenty seconds, you could decide to take it off at ten thirty-six and twenty seconds.

DO NOT LET THE WATER COME TO A BOIL.

If the water comes to a boil, some of the electrical energy will be used to change water into steam, and will not raise the temperature of the water. If your water comes to a boil, stop and discard the boiling water in a safe manner (call your teacher). Then go back to Step Two and start over, but this time don't heat the water for such a long time.

Step Five: Take the pot off at the right time and immediately measure the temperature and how many minutes the pot was heated.

Step Six: Unless your teacher tells you not to, unplug the hot plate. Put the plate and the hot water in a safe location where no one will accidentally touch them.

Notes

Incandescent Versus Fluorescent Efficiency

Objectives

This lesson contributes to the students' understanding of the following idea:

A difference in efficiency can result in a substantial decrease in costs.

Format of the Lesson

Review concept of efficiency

Compare wattage and light output of two lights

Point out ballast losses

Sample survey of lighting in the classroom

Materials Needed

incandescent light bulb fixture it is convenient if this is mounted on a board. Ask for a keyless porcelain lampholder, without pull chain or convenience outlet, such as Paulding Catalog #1625. About $1.50. Or you can clamp a trouble light in a ring stand. In any case, a bare bulb, without shade or reflector, is needed.

incandescent light bulb see below for choice of wattage.

fluorescent bulb and fixture with screws removed so that the top can be lifted to show the ballast. The wattage should approximately match that of the incandescent. Here are some pairings:

A 40-watt incandescent with a 40-watt (47¼") fluorescent. Forty watts is a realistic size for household incandescents, and this is the brightest, easiest-to-see combination. But single-tube, 40-watt fixtures are hard to find, and cost about $20 when you do.

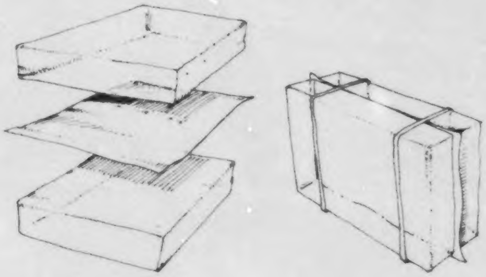
A 25-watt incandescent and a 22-watt "circiline" fluorescent. The fluorescent is available as part of a package to screw into existing lamp sockets (e.g., Star Lite Model No. 1000-2B, about $12.50). If you use this, tilt the bulb so that both sides of the ring are visible from the position of the photometer.

A 15-watt incandescent and a 15-watt fluorescent. The advantage here is that the 15-watt fluorescent is readily available in such configurations as Westinghouse's "Luma-Stick" (plastic fixture and lamp for about $17.25). It is hard to show the ballast on such fixtures, however, and the light is fairly dim if you cannot darken your room.

photographer's light meter an incident light meter that reads in footcandles is preferable (the kind with a white plastic disk or hemisphere). If the only meter available is a reflection meter, take readings off a piece of light gray paper. Ask the meter's owner to explain the technique.

OR

paraffin photometer which can be made by cutting a ¼-pound block of paraffin in two, separating the two pieces with a sheet of aluminum foil, and holding the assembly together with two rubber bands.



meterstick

overhead transparency of survey form

Demonstration

Review the concept of efficiency as a ratio of the energy we get out in the form we want it to the energy we put in. Ask the class what form of energy we want from an electric light. What form of energy do we put in?

Display two lights, one 40-watt incandescent and one 40-watt fluorescent. Point out that each is marked 40 watts. Darken the room and plug them in. Which appears to put out the most light?

Tell the class we will try to get a more exact measure of the relative brightness of the two lights.

If you are using a light meter, ask a group of students to test the light outputs with the light meter.

If no light meter is available, the difference in brightness can be compared through the following activity.

Place the incandescent light on one end of a long table. Exactly one meter from it, put the paraffin photometer, with one side facing the light. Place the fluorescent lamp on the other side of the photometer, a meter away from the photometer.

Have students observe the edge of the photometer. The incandescent light will look yellower than the fluorescent; try to ignore this. It may help to cut a small hole in a piece of black construction paper and put it over the photometer. Are the two sides of the photometer equally bright? (ANS: No, the fluorescent side is brighter.)

We can slide the fluorescent farther away until the two sides are the same brightness, and this gives us a rough way of estimating the relative brightness of the two lights.

Teacher Background

Light falls off as the square of the distance. The following table, which is simply squares, can be used to compare brightness:

If the incandescent is at one meter and the fluorescent at the given distance, then it will be the given multiple brighter.

1.1 meters = 1.2 times brighter
1.2 meters = 1.4 times brighter
1.3 meters = 1.7 times brighter
1.4 meters = 2 times brighter
1.5 meters = 2.25 times brighter
1.6 meters = 2.6 times brighter
1.7 meters = 2.9 times brighter
1.8 meters = 3.2 times brighter
1.9 meters = 3.6 times brighter
2 meters = 4 times brighter

So we can conclude that, watt for watt, we do get more light from the fluorescent.

The Ballast

Tell the class that there is another factor we must be aware of. Unlike an incandescent bulb, the bulb wattage of a fluorescent does not tell us the entire electrical consumption of the light. When a fluorescent is operating, there is an arc inside the tube that is almost a short circuit. To keep too many amps from flowing through the arc, which would burn out the tube and all the fuses, fluorescent lamps include a device called a ballast. The ballast limits the number of amperes flowing through the tube.

With the fluorescent unplugged, remove the cover and point out the black box that is the ballast. Unfortunately, the ballast also consumes energy. Invite students to feel it. It will be hot. It converted some of the electricity flowing through it to heat.

So, in calculating the power consumed by fluorescents, we shouldn't use lamp wattage, but lamp-plus-ballast wattage.

Surveying a Room

Pass out the survey form and ask the students, as homework, to see how much difference more efficient lights would make in some particular room. They can choose the room; any room that has some incandescent lighting (the more, the better). To show how it's done, do a practice run in class.

If your classroom has no incandescent lights, consider making a class data-gathering visit to an area of the school where there are some.

After collecting data, return to the class to analyze them. You may find an overhead transparency of the form useful in showing how to fill it out.

The form is mostly self-evident, though it is necessary to walk the students through an example so that they understand how to use it. One area of potential confusion is the "hours per week" column. We find this figure by estimating the number of hours each individual bulb was on and then adding to get a total for all bulbs of that wattage. Be sure students do not think that they can find "hours per week" by multiplying the number of bulbs by some average figure. Thought and scratch paper are necessary.

Projects for Independent Investigation

1. Most light bulbs are now sold with their light output in lumens marked on the side of the package. In the supermarket, make a list of the wattage and lumens of as many bulbs as you can find. Can you find a relationship between wattage and efficiency (lumens per watt)?
2. Some incandescent light bulbs are made to last longer than others. Frequently, the expected hours of life are marked on the package. Collect data in the same way as for Project 1. Can you find any relationship between how long a bulb is expected to last and its efficiency?
3. Fluorescents come in different colors, like warm white, deluxe warm white, daylight, cool white, and so forth. Are bulbs of one color more efficient than others? How could you demonstrate this experimentally?

Lighting Efficiency Survey

Does using more efficient devices really make a difference? In this activity, you will survey the electric lighting now being used in a particular place, such as your schoolroom, bedroom, the gymnasium, or any other place where incandescent lighting is being used. List all the incandescent lights by wattage, using one line per wattage, and tell how many of them there are. Estimate how many hours each bulb burns in a week and find the total hours for all bulbs of that size. Multiply by watts to find the kilowatt-hours consumed each week by each wattage.

Many rooms are overlit; in some there is not enough light. Do not be concerned about that now. We are only interested in finding out what we could save by using a more efficient light source.

Table 1. Incandescent Lights

	Watt rating	Number of bulbs	Hours per week	kWh per week
1				
2				
3				
4				
5				
6				

Total kilowatt-hours per week = ______ kWh

How much does the electricity to run these lights cost per kWh? $ ______ kWh

Total Cost of Light

$ ______ per kWh x ______ kWh = $ ______

Now lets replace the incandescents with fluorescents. Here are some *approximate* practical equivalents. The lumen is a unit that measures light.

Incandescent wattage	Light output*	Fluorescent lamp wattage	Lamp+ballast wattage	Light output*
25-watt	235 lumens	6-watt	8-watts	230 lumens
40-watt	455 lumens	13-watt	19 watts	655 lumens
60-watt	870 lumens	20-watt	26 watts	1110 lumens
100-watt	1750 lumens	40-watt (circiline)	56 watts	2055 lumens
150-watt	2880 lumens	40-watt rapid start	52 watts	2779 lumens
200-watt	4010 lumens	two 40-watt rapid start	94 watts	5280 lumens

*Both incandescent and fluorescent lamps dim with age. The output of the incandescents is given for brand-new bulbs; for the fluorescents, when they have passed 40% of their rated average life.

Table 2. Fluorescent Replacements

How many fluorescents of what wattages would be needed to replace the incandescent lights in Table 1? For each line of Table 1, make a line in this table.

	Fluorescent lamp wattage	Lamp+ballast wattage	Hours per week	kWh per week
1				
2				
3				
4				
5				
6				

Total new kilowatt-hours per week = ______ kWh

Kilowatt-Hours Saved

kWh consumed by incandescents replaced = ______ kWh

kWh consumed by fluorescents added = – ______ kWh

kWh saved ______ kWh

times cost of a kilowatt-hour x $ ______

utility charges saved in one week = $ ______

utility charges saved per year = $ ______

Question: In what room of the school would replacement of incandescents by fluorescents save the most utility charges? In what room of your home?

Notes

Systems Efficiency

Objectives

This lesson contributes to the students' understanding of the following concepts:

To judge the efficiency with which a machine or process uses energy, we must examine the efficiency of the system of which that machine or process is a part.

Format of the Lesson

Preliminary discussion

Completion of water heater worksheet

Discussion of results on the water heater worksheet

Presentation of electrical generating system

Explanation of calculation of system efficiences

Calculation of electrical system efficiency

Comparison of electric and gas water heaters

Final discussion and summary

Materials Needed

worksheets **Estimate of Where the Annual Energy Input to Residential Water Heaters Goes**, one per student.

overhead transparency **Electrical System** (optional).

Preliminary Discussion

Review the previous activity when the efficiency of the hot plate pot system was calculated. Review the definition of efficiency.

Review any independent investigations or homework assignments completed by students involving efficiency of pots, lights, etc.

Announce that we will now compare some efficiencies of another way of heating water, namely home water heaters.

Distribute the worksheet on water heater efficiencies.

Completing the Worksheet

Help students complete the calculations indicated on the worksheet.

Discuss which type of water heater seems to be most efficient in converting its energy input into heat in water.

Ask where the electrical water heater got its energy. There may be a number of credible answers, for example, from hydroelectric plants, from coal-fired boilers, and so forth. Tell the students that for the sake of comparison we will examine the case in which the electricity came from the power plant fired by natural gas (about 18% of the electricity generated in the United States in 1979 did come from natural gas). This way we are comparing two different ways of using the same energy source.

From Natural Gas to Electricity at the Wall Receptacle

Ask the students what must be done to make electricity from natural gas. On the chalkboard create a diagram of the electrical generating system similar to that shown in the drawing on the next page, or use an overhead transparency. You will need to give students some of the information.

Point out that each of the parts of this system has its own efficiency, just as the water heater has a particular efficiency. For example, the boiler of the power plant converts the chemical energy of natural gas to heat energy in steam. Of course, some of the heat will not end up in the steam but will be lost in heating the equipment itself, and some will go up the smokestack as heat in the flue gases. Because of this a typical boiler has an efficiency of about 77%.

Modern power plant steam turbines typically have an efficiency of about 45%.

The electrical generators connected to the steam turbine change the mechanical energy into electricity. Large generators like these have an efficiency of about 99%. Review that this means that only 99% of the mechanical energy we put in comes out as electrical energy; 1% escapes as heat.

Perhaps the hardest part of the system to think of in terms of efficiency is the transmission system itself, which includes transformers, wires, switches, and so forth. Whenever electricity flows through a wire the wire is heated, because all wires have some resistance. Because of heating wires, transformers, and so forth we don't get out of an electrical transmission system all the energy that we put into it. A 300-mile transmission system will have an efficiency of approximately 91%.

So, our problem now is, if we know the efficiencies of each of the components, how can we calculate the efficiency of the system? Or to say it another way, how much of the energy we put into the boiler will we get out of the water heater?

Calculating System Efficiencies

Imagine a system that has only two components. Component A has an efficiency of 50% and component B has an efficiency of 20%. Make a drawing like this on the chalkboard.

$$\overset{50\%}{\boxed{A}} \qquad\qquad \overset{20\%}{\boxed{B}}$$

Suppose we put in 100 calories. What will we get out of A? (ANS: 50% of 100 calories = 50 calories.)

$$100\text{ calories} \longrightarrow \overset{50\%}{\boxed{A}} \longrightarrow 50\text{ calories} \longrightarrow \overset{20\%}{\boxed{B}}$$

So, what will we be putting into component B? (ANS: 50 calories.) What will we get out of component B? (ANS: 20% of 50 calories = 10 calories.)

$$100\text{ calories} \longrightarrow \overset{50\%}{\boxed{A}} \longrightarrow 50\text{ calories} \longrightarrow \overset{20\%}{\boxed{B}} \longrightarrow 10\text{ calories}$$

What is the efficiency of the whole system?

Answer: $$\frac{\text{energy out}}{\text{energy in}} = \frac{10\text{ calories}}{100\text{ calories}} = 10\%$$

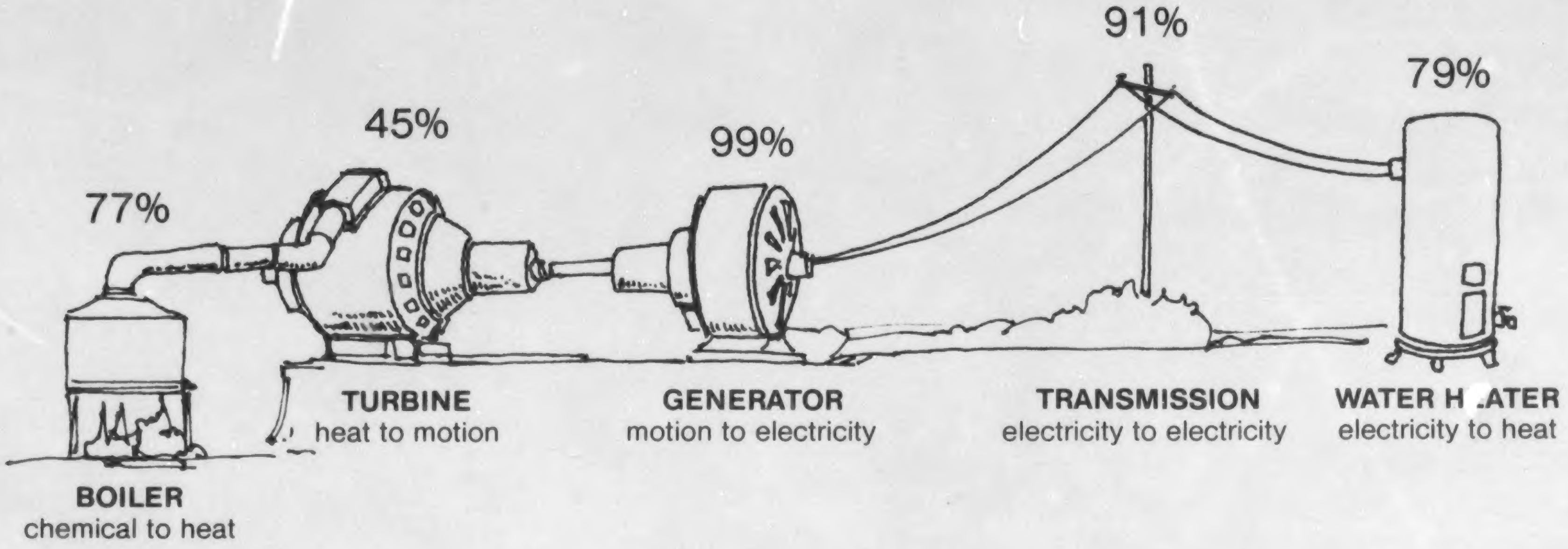
Is there a way of calculating the system efficiency without actually calculating what's left after each step? Some students may perceive there is: if not, point out that multiplying the efficiences of all components gives the system efficiency: i.e.,

$$50\% \times 20\% = 10\%$$

Back to the Water Heaters

Now let's look at the water heaters again. The system efficiency of the electric water heater is:

$$\underset{\text{boiler}}{77\%} \times \underset{\text{turbine}}{45\%} \times \underset{\text{generator}}{99\%} \times \underset{\text{transmission}}{91\%} \times \underset{\text{water heater}}{79\%} = 25\%$$


77%
BOILER
chemical to heat
45%
TURBINE
heat to motion
99%
GENERATOR
motion to electricity
91%
TRANSMISSION
electricity to electricity
79%
WATER HEATER
electricity to heat

Final Discussion

At first, at 79% compared to 46%, the electric water heater looked much more efficient than the gas water heater. Now which looks more efficient?

The smart way to evaluate energy is to look at the whole system, not just a piece of it.

Answers to Homework

I. Here are some possibilities, many of which one would not expect the students to be aware of. (They are only asked to think of two or three.) Also, this list is not exhaustive. In deciding whether a proposed component is actually a part of the system, ask yourself whether it could have an efficiency. Could more energy go in than came out in the desired form?

1. Fusion in sun, transmission as radiation, photosynthesis in plants, digestion in cow, burning in stove-pot system.
2. Fusion in sun, photosynthesis in plants, geological processes, petroleum extraction, petroleum refining, transportation of fuel, burning of fuel in diesel engine, generation of electricity, use of electricity in motor.
3. All the steps up to a petroleum fuel as outlined above, then, assuming the battery was charged by the car and not an AC battery charger, burning fuel in auto engine, generation of electricity, charging of battery, electric motor.
4. Processing of raw materials for battery (this is a step because it is the supply of energy to the processing which puts the latent chemcial energy into the materials), battery converts chemical energy to electricity, bulb converts electricity to light.
5. Fusion in the sun, photosynthesis in plants, respiration in you, bicycle.
6. The student must make an explicit assumption about where the electricity is coming from. Suppose it's nuclear. Fission in reactor, generation of steam, production of motion in turbine, motion to electricity in generator, transmission, electric motor, compressor.

II. Five percent (5%).

Homework Assignment

I. Here are some uses people make of energy. For each use, try to think of at least two or three other parts of the system the energy would have gone through before it reached the use described.
1. In an iron stove, a villager in India burns dried cow dung to cook a meal.
2. Electric motors turn the wheels of a diesel-electric locomotive.
3. The electric starter on an automobile turns the engine over, but it won't start yet.
4. A policeman's flashlight picks out a burglar breaking into a store.
5. You bicycle to school.
6. An air conditioner cools a house.

II. Here are the efficiencies of various parts of the automotive system. Calculate the system efficiency.

Production of crude oil	96%
Refining of crude oil	87%
Transportation of gasoline	97%
Thermal efficiency of auto engine (only part of the heat is changed to motion)	29%
Mechanical efficiency of engine (some of the motion goes to the fan, etc.)	71%
Rolling efficiency (energy lost flexing the tires, for example)	30%

III. Read the pages in the booklet with the headline, "Energy, Rules of the Game."

Calculating the Efficiency of Water Heaters

Estimate of Where the Annual Energy Input To Residential Water Heaters Goes*

(in hundreds of thousands of Btu's)

Type of water heater	Total heat input	Heat lost through tank surface	Heat lost up flue		Net usable heat
			Burner firing	Pilot light	
50-gallon electric	150.3	31.8	—	—	118.5
40-gallon gas/LPG	260.3	91.0	31.1	19.7	118.5
40-gallon fuel oil	271.9	95.0	36.7	21.7	118.5

*Assuming a 750 Btu/hr pilot, and efficiency of heat transfer to the water of 70 percent for gas/LPG units and 67 percent for oil units.

1. What is the efficiency of the electric water heater?

$\frac{\text{net usable heat}}{\text{total heat input}} = \frac{11,850,000}{15,030,000} =$ ______________ %

2. What is the efficiency of the 40-gallon gas water heater?

$\frac{\text{net usable heat}}{\text{total heat input}} =$ ______________ = ______________ %

3. What is the efficiency of the 40-gallon fuel oil heater?

$\frac{\text{net usable heat}}{\text{total heat input}} =$ ______________ = ______________ %

4. Which is the most efficient? ______________

Are Energy Flows Reversible?

Objectives

This lesson contributes to the students' understanding of the following concepts:

Most energy conversions result in the production of some heat.

Some energy flows are impossible, such as a flow of heat from a cold object to a hot object.

When an impossible energy flow looks possible, it is because we are only looking at part of the system.

When mechanical energy is converted to heat, there is no way to put the universe back the way it was before the conversion happened; that is, we cannot convert all the heat back to mechanical energy.

Format of the Lesson

Demonstrate motor-generator chain

What happened in the perpetual motion machine?

Can all energy conversions run in reverse?

Irreversible processes and the future of the universe

Materials Needed

motors six or more miniature permanent magnet motors, of the type used with the solar cell. Please see the lesson plan, "Converting Heat and Light to Electricity," for prices and names of suppliers. Better quality motors are an advantage in this demonstration, since they will rotate over a wider range of voltages.

cardboard a piece about 25 cm long and 5 cm wide, bent into a long V-shaped trough.

masking tape

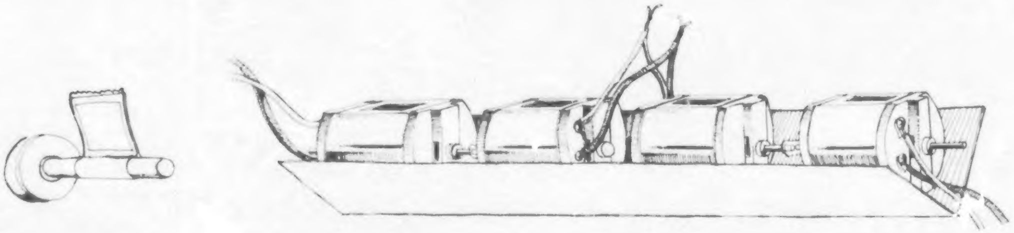
dry cells two or three #6 cells connected in series, depending on motor used, or other power supply with appropriate voltage and amperage.

plastic tubing with an inner diameter a bit smaller than the outer diameter of the shafts of the motors, about 6 inches long. The fit is not critical. This type of tubing can be obtained from hobby stores as fuel-line tubing used with model airplanes.

To Construct the Apparatus

Before class, you will need to construct a demonstration apparatus. This takes about ten minutes; longer if you solder the connections.

Small permanent magnet motors, such as we used for the solar cell, can also function as generators. We are going to connect a string of these, motor-generator-motor-generator.



Connect the motor's shaft to the shaft of the generator next in line with an inch of plastic tubing, by forcing the tubing over one shaft and then the other. The plastic tubing acts as a universal joint, which accommodates any slight misalignment in the two shafts. Keep the shafts in rough alignment by taping the paired motors and generators into the cardboard trough.

To carry the electricity produced by the generator to the motor next in line, just twist the stripped ends of their wires together.

To make it easier to see the rotation of the shafts, wrap a bit of transparent tape around the tubing, with a bit of colored paper struck to the ends of the tape.

Before class, experiment with different voltages to determine how high a voltage can be used without damaging the first motor.

Demonstrating the Motor-Generator Chain

Using the chalkboard, explain to the class that you have a design for a perpetual motion machine, using an electric motor to turn a generator, which generates electricity to turn the motor. (Loud guffaws, we hope.) However, for your trial run, you've connected the generator to a different, but identical, motor, because you first wanted to see how things would work out.

Once the class understands the nature of the apparatus, ask them to predict what's going to happen. Then connect the first motor.

With very poor motors, you may find that even the second motor will not turn over. Give its shaft a twist to see if you can feel any torque. Better motors may show rotation (though, of course, at greatly reduced speeds) through several motor-generator pairs.

If you have a meter, have students measure the voltages at the generator-to-motor connections. Write them on the chalkboard as a sequence.

Have students count the revolutions per minute of the bits of paper, where it is slow enough to be countable. List these data in sequence on the board.

You may wish to have a student organize the data (voltage, rpm, or both) into a rough graph on the chalkboard.

What Happened in the Perpetual Motion Machine?

Ask students to describe what is happening in the apparatus. We know that energy is not destroyed; energy-in must equal energy-out, but the last motor isn't rotating as fast as the first. Why not?

Students may point out friction as one cause. Ask what form of energy is converted to what in friction.

Some students may be able to identify electrical resistance as one source of loss in the motors and generators. Again, ask what form of energy is converted to what by electrical resistance. If students are not familiar with resistance, ask them to feel the motors and generators after they have been running for a while. They will be quite warm, warmer than you could make them by just spinning their shafts at that speed. The extra heat comes mostly from the resistance of the wires in the motor.

Summarize that our perpetual motion machine clearly won't work, because part of the electricity, and part of the motion, are being converted to heat. This is true of almost every use of energy we make: part of the energy is converted to heat. For the perpetual motion machine to work, all the heat would have to be converted back to motion (or electricity). That would not violate the principle of conservation of energy, but — is it possible?

Can All Energy Conversions Run in Reverse?

Point out to the class that they have done many different energy conversions, both in class and out. We know from our own experience that it is possible to convert at least some of any kind of energy to any other kind.* We have noticed that energy is conserved; that we get out exactly as much as we put in, no more, no less, though usually not all in the form we wanted.

Now let's think about a slightly different question. Suppose we have some energy in form A, and we change it to form B. Can we reverse things and change **all** of B back to A, so that we put the universe back exactly the way it was before we made the first conversion?

To help us think about this, tell the class that you will read some examples of energy flows. These examples are just made-up; they may or may not be real. Then you'll ask two questions. Could energy be conserved in such a flow? Is this flow or conversion possible?

1. We have some hot water and some cold water. Heat flows from the hot water to the cold water until they're both the same temperature.

a. Could this happen in such a way that we would end up with the same amount of energy that we started with? (ANS: Yes — always does.)

b. Is this possible? (ANS: Sure.)

2. We have some hot water and some cold water. Heat flows from the cold water to the hot water, until the hot water boils away and the cold water freezes.

a. Could this happen in such a way that we would end up with the same amount of energy that we started with? (ANS: Yes.)

b. Is this possible? (ANS: No.) Some students may object, (and, if they don't, you should propose, as a possible counter-example) that a refrigerator takes heat out of the cold water in the ice cube trays and puts it into the warm air of the room. This is true — but only tunnel vision lets us think this is an example of heat flowing from cold to warm. For the refrigerator to do this, there had to be a flow of heat from hot to cold somewhere else that was greater than the flow between the ice cube trays and the room air. Think about where the electricity to run the refrigerator came from. Perhaps from a coal-fired or nuclear power plant, in both of which heat is flowing from hot (the boiler or reactor) to cool (the air or water). This is even true of hydroelectricity. (Think about the flow of heat in the water cycle.) Therefore, the **net** effect, in the case of the refrigerator, was a flow from hot to cold, not cold to hot.

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*True, we haven't experimented with nuclear energy. In nuclear energy, mass is converted to energy. Is energy ever convertible to mass? Have we ever done so? Hint: Think about relativity.

3. A brick falls and hits the floor, warming it very slightly (conversion of motion to heat).

a. Could this happen in such a way that we would end up with the same amount of energy that we started with? (ANS: Yes.)

b. Is this possible? (ANS: Of a certainty.)

4. We place a brick on a warm spot on the floor. It flies up to the ceiling and the floor gets a little colder.

a. Could this happen in such a way that we would end up with the same amount of energy as we started with? (ANS: Yes.)

b. Is this possible? (ANS: No.) Actually, rather than being strictly impossible, it is only so unlikely as never to happen. If the motion of the molecules in the brick (due to its heat) were, for an instant, not random but exhibited some preference for a particular direction, the brick would move in that direction. This is not observed to happen because molecules, being so small, are very numerous in visible objects, which are big. The more random events one is averaging out, the less likely anomalous outcomes become. (The more coins you flip, the closer the heads-to-tails ratio comes to 50:50. If you only flip four times, chances are one in 16 you will get all heads.)

5. Carbon and oxygen combine, producing hot carbon dioxide.

a. Could this happen in such a way that we would end up with the same amount of energy that we started with? (ANS: Yes, we always do.)

b. Is this possible? (ANS: It happens at every barbeçue.)

6. Carbon dioxide, at the temperature produced by burning that amount of carbon, decomposes into cold carbon and oxygen.

a. Could this happen in such a way that we would end up with the same amount of energy that we started with? (ANS: Though not obvious to students, it could. The energy is latent chemical energy in the carbon and oxygen.)

b. Is this possible? (ANS: No.) Fires aren't observed to run backwards and change all of the heat back into chemical energy. (By adding extra energy it would be possible to break down the carbon dioxide molecule. But then we would have added extra energy.)

Make a chart on the chalkboard of the six conversions discussed

Forward	**Reverse**
1. Heat flow from hot to cold.	2. Heat flow from cold to hot.
3. Motion changes to heat.	4. **All** the heat produced changes back to motion.
5. Fuel and oxygen change to heat and flue gases.	6. Hot products of combustion change to cold fuel and oxygen.

Ask the class, what do we notice? All the possibles are on one side, all the impossibles on the other.

Summarize that there are some kinds of energy conversions that don't violate the principle of conservation of energy but, nevertheless, never occur, such as heat flowing from cold to hot.

The Direction of the Universe

Because some energy flows are impossible, some changes are permanent. The universe cannot be put back the way it was before these flows occurred.

Heat flows from hot to cold, but not from cold to hot. As a result, there is a tendency for everything in the universe to become the same temperature. The interestingly varied temperatures of people and stars that we now observe seem to be temporary.

Mechanical energy can be converted to heat by friction, for example; but it is impossible to convert all the resulting heat back to mechanical energy. As a result, orderly motion gets converted to random motion of molecules.

This means that there is a direction to the universe. Other forms of energy often get converted to heat, and the heat is not being converted back. Instead, heat is being transferred from matter at higher temperatures to matter at lower temperatures; and the lower the temperature, the harder it becomes to convert a part of that heat to forms like motion or electricity.

Notes

Can Heat Do Work?

Objectives

This lesson contributes to students' understanding of the following concepts:

Even "primitive" societies need much of of their energy in the form of mechanical energy.

For thousands of years, people searched for a practical way of changing heat to mechanical energy.

Materials Needed

flask with one-hole stopper

glass tube

ring stand

heat source such as a lab burner or can of Sterno.

To make the aeolipyle:

tin can square, with a press-fit lid, the sort tea comes in (e.g., Twinings).

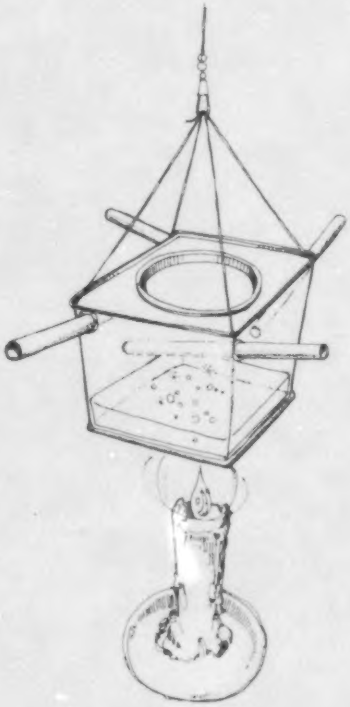
silicone glue-sealer about $3.20 for 83 mL.

plastic drinking straws four. The kind used as stirrers for alcoholic beverages work best; they have a smaller inner diameter, which increases the velocity of the escaping gas. Plastic straws may melt unless great care is taken when using the apparatus. Metal tubes can be substituted.

ball-bearing swivel such as Sampo No. 3SB, available from sporting goods stores at three for about $2.50.

string

To Construct the Apparatus



Please refer to the illustration. To construct the apparatus, punch a hole in each of the four sides of the can, near the upper right corner of each side. A nail with the same outside diameter as the straw can be used for this. Punch a second, much smaller hole through each corner of the top of the can. (If you wish, the holes can be made by drilling.)

Using silicone glue-sealer, cement the straws into the can. When you push the straw through the hole, tilt it so that it is visible through the top of the can, and squirt a dab of glue onto the straw about a centimeter from its end. Then push the straw against the side of the can, keeping the end of the straw inside the can as high in the can as possible, so that steam, and not water, will escape through it. Seal the opening around the straw with more glue. Put all four straws into the tin this way.

Suspend the can from a swivel by threading string or fishing line through the holes in the corners, as shown in the drawing. These holes will probably also have penetrated the can, so seal them with a dab of sealant as you did the holes through which the straws were put.

Notice that this apparatus has a built-in safety valve: the press-fit lid, and the silicone sealer on the other holes.

A more durable apparatus can be made by soldering metal tubes to the can.

Establishing the Problem: Getting Mechanical Energy

Review that, thousands of years ago, people used fuel to keep warm and to make things like pottery and metal tools. Ask the class for examples of how people did these things.

Ask the class what other activities people needed energy for thousands of years ago. (ANS: They needed energy to plant crops, build houses, etc.) If you get no response, ask how people got fed, sheltered, clothed.

What kind of energy are we describing? (ANS: Mechanical energy, motion.)

So, people needed mechanical energy. But just about the only source of mechanical energy back then was muscle; human muscle or animal muscle.

Some people thought there might be a way of getting mechanical energy out of a fire. Let's look at an idea we find in a book written in the 1st century A.D. by a man named Hero of Alexander.

Demonstration: Heat to Motion

Hero might have begun by observing something like this:

Boil some water in a flask with a one-hole stopper and tube. When steam begins to escape from the tube, ask the class what observations they can make. If necessary, prompt:

Is anything moving? (ANS: The boiling water, the steam.)

So, we've found that we can change heat into motion by boiling water. However, it doesn't look like a way of getting useful mechanical energy, does it? But Hero had an idea.

The Aeolipyle

CAUTION: You do not want the apparatus to spray the class with boiling water. To prevent the boiling water from reaching the level of the straws,

1) Fill the metal can no more than ⅓ full of water, and

2) Do not apply an excess of heat. When the water begins boiling, either reduce the flame or raise the can until boiling is just adequate to maintain rotation.

Suspend the can over a burner, using a ring stand.

Ask the class what makes the can rotate.

Is the rotation very powerful? Try stopping the rotation with a stick, from above.

Ask the students if they think we could use the device to do useful work. Most will agree that this device, as it is, could not produce useful work.

Hero's gadget works on the same principle as a rocket. It did not develop into a useful engine for doing work; in fact, almost 1,800 years went by before people succeeded in making a reliable, powerful engine that changed heat into mechanical energy, and it worked on an entirely different principle. But the important thing is that almost 2,000 years ago people knew that the energy from a burning fuel could be converted to work, they just couldn't find a practical way of doing it.

Projects for Independent Investigation

1. Design an engine that would use the force of escaping steam, like Hero's, but would have some way of taking the energy off on a rotating shaft.

2. Describe to the class how another of Hero's inventions worked.

Notes

Heat Engines and Sadi Carnot

Objectives

This lesson contributes to students' understanding of the following concepts:

There are theoretical limits to how efficient ways of transforming one kind of energy to another can be.

The practical efficiency can never reach the theoretical limit on efficiency, owing to losses such as friction.

Many of the devices we use to produce mechanical energy are heat engines, which transfer heat from a high-temperature reservoir to a low-temperature reservoir.

The theoretical limit on the efficiency of such engines is determined by the difference between the high and low temperature.

Format of the Lesson

How we get work

Heat engines

  sources and sinks

  working fluid

  cycles

Sadi Carnot's question: maximum efficiency

Absolute temperature

Maximum theoretical efficiency of a heat engine

Materials Needed

None. This lesson is essentially a chalktalk.

Engines

Ask the class what devices we use to produce work, or mechanical energy. List some on the chalkboard. The list might include:

gasoline engine

steam turbine

electric motor

steam engine

diesel engine

gas turbine

waterwheel

Leave the list on the board.

Going Back a Few Years

Ask the class which of these devices people made practical use of around 1800. (ANS: One was the steam engine.)

Most of the devices we use today were not available then, but the steam engine was. Around 1800, and in the years thereafter, the French Revolution occurred in Europe, followed by the Napoleonic Wars in which France first conquered most of Europe and then was defeated by England and her allies.

After the war, a young French engineer whose name was Sadi Carnot got to thinking about steam engines. He felt one reason the French had lost the war was that they were not as advanced in steam power as the English.

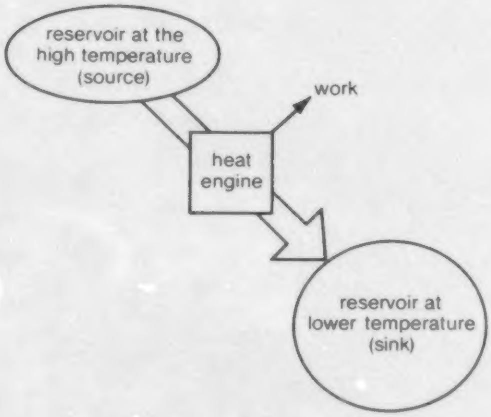
The English approach to improving steam engines was largely trial and error. Carnot took another approach. He asked himself, what do steam engines do, and how could they do it perfectly. Engineers at that time recognized very well that a steam engine converted heat to work.

Heat Engines

We call a device that transforms heat into work a heat engine. Ask the class to study the list on the board. Which of these devices are heat engines? (ANS: Everything but the electric motor. Windmills and waterwheels really are heat engines if you look at the wind and water cycles.)

Erase the names of all the devices that are not heat engines.

Carnot tried to look at the steam engine in as general a way as possible, and he saw that in any heat engine there is a flow of heat between a reservoir at a high temperature, and another reservoir at a colder temperature. Draw the following diagram on the chalkboard:


reservoir at the high temperature (source)
work
heat engine
reservoir at lower temperature (sink)

In the steam engine, the source is the burning fuel under the boiler, and the sink is the cooling water flowing through the condenser. Notice that, in practical heat engines, the temperature of the sink is that of the surroundings — the air, the local river, or the ocean. It doesn't pay to refrigerate water for cooling.

On the chalkboard, put the column headings "source" and "sink" to the right of the "heat engines" heading. Ask the class if they can identify the source and sink for each of the heat engines they have named. For example:

HEAT ENGINES	SOURCE	SINK
steam engine	burning fuel	cooling water in condenser
steam turbine	reactor (for example)	ditto
gasoline engine	burning gasoline	atmosphere

Working Fluid

Another thing we notice about heat engines is that they all use a "working fluid." To the physicist, "fluid" means any substance that can flow. So liquid is a fluid, and gas is also a fluid. In the steam engine, steam is used to transfer heat from the high-temperature reservoir to the low-temperature reservoir. Look at the list of heat engines on the board. Do they all use a working fluid?

Cycles

Carnot noticed something else about the steam engine. It works in cycles. If you wait, it comes back to a point where everything is just as it was, except that some heat has been transformed to work.

Look at the list of heat engines. Do they all operate in cycles?

Carnot's Question

Here is the question Carnot tried to answer:

"The question has often been raised whether the motive power of heat is unbounded, whether the possible improvements in steam engines have an assignable limit, — a limit which the nature of things will not allow to be passed by any means whatsoever, or whether on the contrary, these improvements may be carried on indefinitely. We have long sought to ascertain whether there are in existence agents preferable to steam for developing the motive power of heat; whether atmospheric air, for example, would not be preferable. We propose now to submit these questions to a deliberate examination."

In other words, Carnot was asking, is there any limit to the efficiency of a heat engine? How much of the heat flowing through the engine can be transformed into work? Does it depend on whether the engine uses steam, or air, or some other working fluid?

To try to answer this question, Carnot imagined a perfect engine and how it would have to work. Partly, he did this by noting things about the steam engine, such as that there are two reservoirs, and that it operates in a cycle. Carnot proved it would be impossible for any engine to convert more heat to work than his imaginary design did, and then he looked at what determined the efficiency of his "perfect engine." We won't try to follow all of Carnot's reasoning, but will simply jump ahead to his conclusions. He proved that whether you used steam or air was irrelevant, and that there **was** a limit to how much of the heat could be transformed to work in his perfect engine, and so in all heat engines. Carnot wrote:

"1. The temperature of the fluid should be made as high as possible, in order to obtain a large production of motive power.

"2. For the same reason the cooling should be carried as far as possible."

Carnot's book was the beginning of the science of thermodynamics. Later, a physicist named Clausius was able to express mathematically how the efficiency of a heat engine is limited by its operating temperature. To understand what he said, we first have to look at something else.

Absolute Scale of Temperature

Physicists have found that there is a limit to cold, a place where molecular motion reaches a minimum. It is called absolute zero, and is at about minus 273.15°C.

The Celsius scale of temperature is based on the properties of water. Zero is the freezing point (approximately, actually the triple point) of water. Physicists use a different scale, the Kelvin scale, which uses the same size degrees as the Celsius scale, but begins at absolute zero. To convert a temperature in degrees Celsius to degrees Kelvin, add 273.15.

Clausius' Formula

Clausius found this way of calculating the limit on the efficiency of a heat engine:

maximum possible efficiency =

$$1 - \frac{\text{absolute temperature of sink}}{\text{absolute temperature of source}}$$

So if we have a steam engine running on steam at 300°C (= 573.15 K), which is exhausted from the engine at 30°C. (= 303.15 K), then

the maximum possible efficiency =

$$1 - \frac{303\text{ K}}{573\text{ K}} = .47\ (47\%)$$

No matter what you do, you can't make a heat engine that receives heat at 573°K and expels it at 303°K that will be able to transform more than half that heat into work. In reality, of course, you would never get as high as 47%, because of frictional losses, heat escaping from pipes, and so forth.

How can you raise the maximum theoretical efficiency? You can make the source hotter, or the sink colder. Making the sink colder is usually impractical. Much of the improvement in the efficiency of heat engines that has been made in the last century has come from finding materials that will still be strong at temperatures of 1,000 degrees.

Homework Assignment

Water in the depths of the oceans is colder than water on the oceans' surfaces. There are plans to use this temperature difference to run a heat engine. Calculate the theoretical limit on the efficiency of such an engine if the surface water is at 27°C and the deep water has a temperature of 6°C.

$$K = {}^\circ C + 273$$

maximum possible efficiency =

$$1 - \frac{\text{absolute temperature of sink}}{\text{absolute temperature of source}}$$

Projects for Independent Investigation

1. Report to the class on the materials used in building gas turbines, and how they have changed over the last 20 years. How have changes in materials affected the operating temperature of the gas turbine?

2. Work is being done on using materials such as carbides and nitrides to line the cylinders of automobile engines. Why would anyone be interested in doing this? What are the prospects for making this innovation practical?

3. The heating of natural waters by the waste heat of power plants has been called "thermal pollution." To minimize thermal pollution, should the plants' boilers operate at as high a temperature as possible or at as low a temperature as possible? Give reasons for your answer.

A Rubber Band Engine

Most heat engines are too difficult for students to build. Here's a fascinating one that is not, but which demonstrates many heat engine principles.

Materials Needed

bicycle wheel rim 26" or 27". By far the cheapest way of getting the parts needed for this engine is to "cannibalize" an old bike. If you purchase a new rim, a steel rim will cost about $9 and an aluminum one $21.

bicycle wheel hub if not scavenged, an economy grade hub can be purchased for about $6. Be sure to get the special axle nuts with the hub.

support for the wheel a temporary support can be made very simply by clamping the axle in a bench vise, or between ring stands. Something more permanent can be made from the front fork, if you have broken up an old bike, or a pair of vertical two-by-fours, or a perforated angle iron fastened to a board. All permanent supports will also require lumber: a large flat board and, in some cases, two-by-fours.

rubber bands #105 rubber bands (Plymouth Rubber Co.). Sold by the pound, about $6.50 a pound at office supply stores. There are 72 bands to a pound, enough for one engine.

rat-tail file or a hand grinder such as a Dremel Moto-Tool.

small S-hooks available in most hardware stores.

4-penny (4-d) finishing nails

6-penny (6-d) finishing nails

nippers linesmens' pliers, or other cutter capable of cutting the nails.

heavy needle-nose pliers to bend the S-hooks.

light preferably a 250-watt infrared bulb (heat lamp), in socket and with a support.

aluminum foil

cardboard one sheet about 30cm by 40cm.

Procedure

Step One: With a file or hand grinder (wear eye protection!) enlarge the spoke holes in the rim so that they are about 8mm wide and 16mm long. Preserve the even spacing of the holes by enlarging all the holes in the same direction (e.g., always file down). Ignore the hole for the stem of the inner tube. Remove burrs and sharp edges with a piece of emery cloth.

Step Two: Using pliers, put a ninety-degree twist in each of the S-hooks, so that one eye can lie in the plane of the hub flanges while the other is perpendicular to it. Attach an S-hook to each hole in the hub. So that the hook won't fall off the hub, use pliers to close the eye of each S which is attached to the hub.

Step Three: Make a mount for the wheel. If you are making a temporary set-up, save the threads on the axle by clamping the vise or laboratory-stand clamps onto nuts on the axle, not the axle itself. If you are making a permanent setup from a bicycle front fork, glue together a stack of blocks on a larger board and drill a vertical hole through them just large enough to hold the stem of the fork. OR, mount vertically two 30" lengths of two-by-four with a spacer about 9.5cm thick between them. OR, if you are using a perforated angle iron, mount it on a board as shown in the drawing. Using a file, enlarge two opposite holes until they are big enough to take the axle of the hub.

Step Four: Put the wheel rim into the mount, and fasten the hub to it. Adjust the inside nuts that hold the ball bearing so that the wheel has as little drag as possible. If you are using a salvaged hub, you may wish to take the bearings apart, flush out old grease with solvent, and apply some light machine oil. A good spraying with WD-40 can have much the same effect.

Step Five: Hold together the ends of the two rubber bands. Push them through one of the enlarged spoke holes in the rim. Place a 4-d nail through each of the loops, then pull the bands tight so that the nails are held against the rim.

Connect the other two ends of the rubber bands to the S-hooks on the hub, one on each side, so that they make a V-shape. Connect the bands from the next spoke hole to the same pair of S-hooks, and from the third spoke hole, to the next, empty, pair of S-hooks. Eventually, there will be two bands on every S-hook.

Repeat until all the spoke holes have been filled.

Step Six: Balance the wheel. This *must* be done carefully if the wheel is to work. To do this, spin the wheel and let it come to rest. Mark the uppermost part of the rim with grease pencil or marker. Spin the wheel again. If it comes to rest at approximately the same place, increase the weight at the top of the wheel by replacing one of the 4-d nails with a 6-d nail. Repeat the procedure until the stopping position is varying by ten cm or so. For fine tuning, clip off a small bit of the bottom-most nail, until the wheel does not seem to come to rest at any particular spot.

Step Seven: Support the light a few inches from the spokes at the bottom left or right of the wheel, Cover a sheet of cardboard about 30cm by 40cm with aluminum foil. Place this "mirror" on the other side of the wheel, facing the light. This reflector heats the other side of the bands with radiant energy that would otherwise escape.

Step Eight: The engine is now ready for testing. Turn on the light. After a few seconds, the wheel should start to turn. If it does not, the most likely causes are that it has not been balanced enough, or that the nuts on the axle are too tight.

Acknowledgements

E.G.Cox invented the basic form of this engine, and provides background information in his article "A Heat Engine Run by Rubber," *Journal of Chemical Education*, Volume 3 No. 6 (June 1954). The clever way of holding the spokes with nails is John Rosenbaum's idea. Thanks to Charmaine Craig for trying out variations.

Explanation

The rubber bands in front of the lamp are heated by absorbing light from the bulb. When they become warmer, they contract. Their contracting lengthens the bands on the opposite side of the hub, and so the hub is pulled out of the center of the rim. This unbalances the wheel and the farther side falls, making the wheel revolve. But as the wheel revolves, the hot bands move into the shade and cool off, while cool bands move into the light, become warm, and contract. So the cycle repeats itself and the wheel continues to turn as long as light is supplied.

Questions for Discussion

Demonstrate the motor without any explanation and then ask, "Why does the wheel turn?"

Give students some time to speculate on this. A number of students will come up with the idea that the wheel turns because it is off-center; however, typically the class divides into two camps as to whether the bands expand or contract. Some students are likely to appeal to the fact they have learned that heated materials expand. Like their medieval counterparts, these arguments can be settled in only one way—by experiment, and this is a excellent opportunity for emphasizing the role of experimentation in science.

A good demonstration is to hang a weight from a ring stand clamp by a rubber band. When the band is heated, the weight will rise.

What is the energy source?

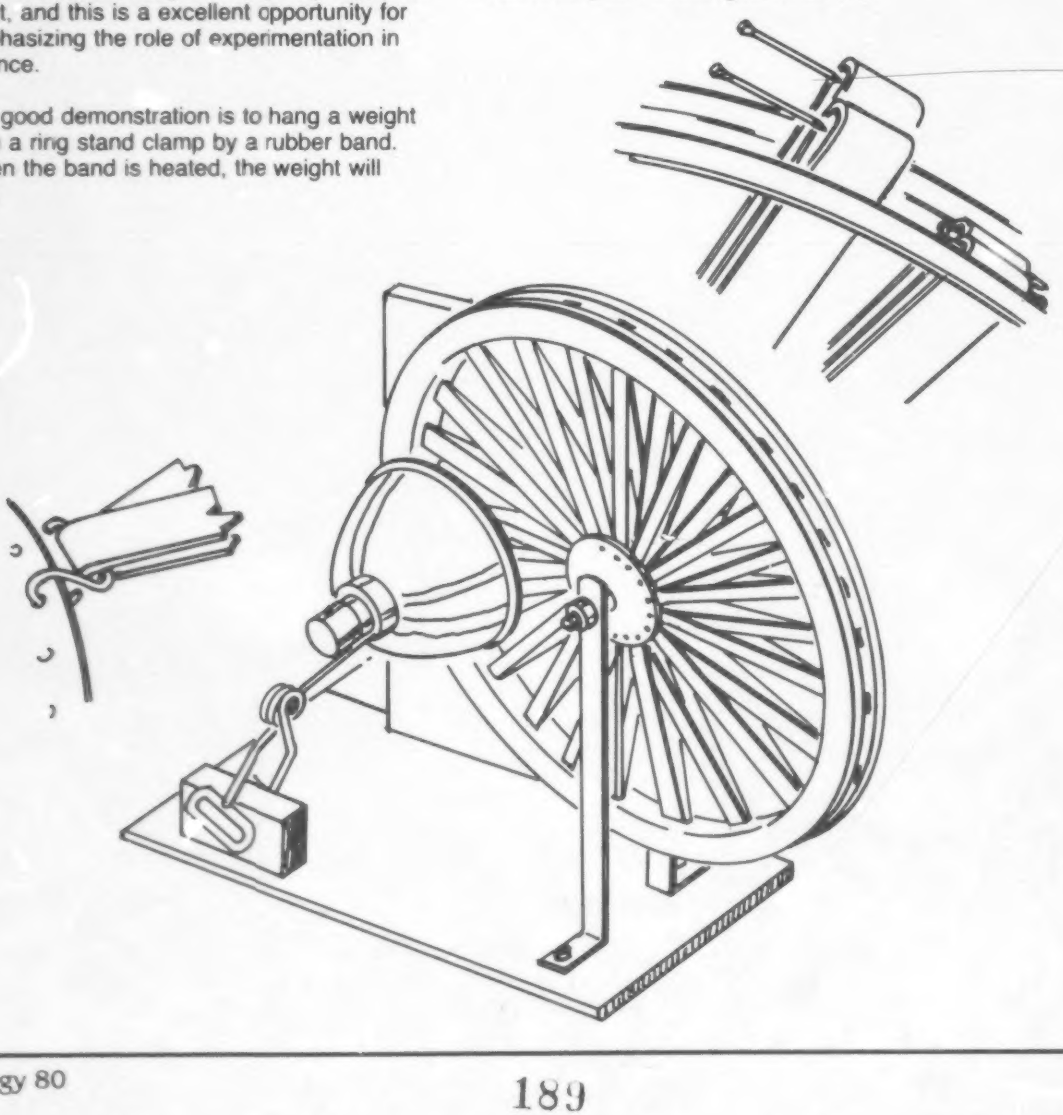
Suppose the light shone equally brightly on all the spokes. Would the wheel turn?

Trace the flow of heat.

Where is the heat source? Where is the heat sink?

Suppose instead of a light shining on the lower-left spokes, there were two blocks of dry ice on either side of the upper-right spokes. Would the wheel turn?

Is this a very efficient engine? Prove it.



Notes

Second-Law Efficiency

Objectives

This lesson contributes to students' understanding of the following concepts:

Many types of energy-conversion devices cannot reach a first-law efficiency of 100%.

Some devices can operate at an apparent efficiency of more than 100%, by drawing heat from their surroundings.

First-law efficiency alone does not tell us whether the method we are using is the best way of using a particular energy input to do a particular job.

The most useful energy sources are those that can be converted entirely to mechanical energy.

We can define other measures of efficiency so that 100% represents the best possible performance using a particular energy input.

Format of the Lesson

What does 100% suggest to people?

What does 100% efficiency suggest to people?

Quality of energy sources

Second-law efficiency

The moral of the story

Materials Needed

heat pump ads and brochures "Heat Pump" is a listing in the Yellow Pages, and you may be able to get brochures by calling local dealers. Writing manufacturers takes longer but may yield more useful literature. Some names and addresses:

Day and Night
P. O. Box 1234
City of Industry, CA 91747

General Electric Company
Central Air Conditioning Business
Department
Louisville, KY 40225

Payne Air Conditioners
16950 E. Chestnut Ave.
City of Industry, CA 91749

York
A Division of Borg-Warner
16350 Manning Way
Cerritos, CA 90701

Lennox Electric Heat Pumps
200 South 12th Avenue
Marshalltown, Iowa 50158

What Does 100% Suggest to You?

Ask the class what 100% suggests to them. For example, what does a grade of 100% suggest? Or soap that is 99.44% pure? (Pure what?) Summarize that we usually interpret 100% to mean the most, or the best.

What Does 100% Efficient Mean?

Let's look at the first-law efficiencies of some devices and systems and see what 100% efficiency means.

1. A very good gas-fired household furnace, one that is highly efficient, will have an efficiency of about 75%. (This is the efficiency of the device in the home, not of the whole gas production, distribution, and use system.) Review that this means 75% of the heat that can be obtained from burning the gas goes into warming the air in the house. The other 25% goes up the chimney.

Suppose the furnace were 100% efficient. That would mean that all of the heat went into the house and none up the chimney. It looks like a furnace that is 100% efficient would be a perfect home heating device. But that is wrong. Although the device would be perfect, what counts is how much heat is brought into the house for a given energy input. There may be other ways of using the gas that might get more heat into the house than by burning it in a furnace. For example, there are experimental gas-powered heat pumps. These are like refrigerators run in reverse, and can take heat from a relatively cool place, like the outdoor air, and move it to a warm place, like the indoor air.

Pass out some heat-pump ads or brochures for students to examine. You may want to draw the pump, inside and outside air, and energy-flow arrows on the chalkboard while talking about the heat pump.

2. Suppose we have an electric heat pump and we compare the energy we put into the heat pump, in the form of electricity, with the heat energy the pump transfers to the air in the house. It will usually turn out that the amount of heat energy that is transferred into the house is at least twice as large as the amount of electrical energy put into the heat pump. Therefore, the heat pump seems to have an efficiency of 200%. Actually, we call this its coefficient of performance, or COP, for short. A heat pump that had an efficiency of only 100% would be a very bad one. For a heat pump, 100% doesn't mean good, it means bad.

3. An automobile engine may have an efficiency of, say, 30%. This looks pretty bad; we have a long way to go until we get to 100%. But as we have learned, it is impossible for a heat engine to convert 100% of its heat to motion. The maximum possible efficiency of a car engine is around 50% (for a diesel engine, which is the most efficient type of production engine). In fact, therefore, a 30% efficient engine is good.

If we are interested in making the best possible use of the energy we have, first-law efficiency does not seem to tell us immediately what we want to know. It doesn't tell us how close we are to the best we can do. So scientists have sought other ways of describing efficiency.

The Quality of Different Forms of Energy

In calculating first-law efficiency, you notice that we made no distinction between different kinds of energy. For example, when we calculated the efficiency of the hot-plate/pot system, we compared electricity to heat in the water. In a way, this is comparing apples to oranges. Some forms of energy are much more useful than others. Electricity is a very useful form of energy. We can easily change it to mechanical energy, heat, light, chemical energy — whatever we need. On the other hand, the heat in warm water is not so useful. Can you think of a practical way of changing the heat in a pot of hot water to any other form of energy? (ANS: No.)

The high-quality forms of energy, those for which people are willing to pay a premium, have something in common. They are all forms of what physicists call work. Mechanical energy is work, and so is electricity.

Heat is not work but, as we learned from heat engines, the higher the temperature we start with, the more the heat we can convert to work. So high temperatures are potentially more valuable than low temperatures. An energy source that will produce a high temperature is a higher quality than one that can only produce a low temperature.

In defining a new measure of efficiency, it would be helpful if it could also warn us how much we are degrading the energy we use, so that we don't use high-quality energy to do a job that could be done by low-quality energy.

Second-Law Efficiency

Physicists have defined a kind of efficiency where 100% represents the best that could possibly be done, and that takes into account the differing qualities of various energy sources. This measure is called "second-law efficiency."

$$\text{second-law efficiency} = \frac{\text{heat or work usefully transferred}}{\text{maximum possible heat or work transferable for same function by any device using the same energy input}}$$

Physicists have ways of figuring out what the denominator of the fraction will be. "Any device" doesn't mean something you could go to a store and buy today, or even ever, but rather where the limit imposed by nature is.

Let's take an example and see how this works out.

A typical home furnace may have a first-law efficiency of 60% That doesn't seem too bad; in fact, it looks pretty good. (After all, a car is only about 8% first-law efficient.) It doesn't look as if it would be worth our while trying to wring out a few extra percentage points. (The nearer a device comes to its theoretical maximum efficiency, the harder it is to make further improvements.) But when we calculate the furnace's second-law efficiency, it comes out to about 8%. In contrast, the second-law efficiency of a heat pump used to heat homes, with a first-law efficiency of 245% (its COP), will be about 11%, or 20% if we can use its waste heat for, say, water heating.

Here are some additional comparisons of first- and second-law efficiencies which you may wish to put on the chalkboard:

	1st Law*	2nd Law
electric water heater	75%	1.5%
gas water heater	50%	2.9%
air conditioner	200%	4.5%
room heater	60%	2.8%

The Moral of the Story

What is the moral of all this? That to use first-law efficiencies to evaluate ways of using energy, we have to be aware of what our options are. A low percentage may sometimes represent the best way we have of doing something; and a high percentage, like that of the furnace, may represent a rather dumb way of doing something. Noticing the second-law efficiency helps keep us from being falsely lulled into the idea that there is little left to do. For example, over the past few decades, engineers have done a superb job of raising the efficiency of combustion-based power plants to very near the theoretical maximum. But completely different methods, such as fuel cells, have other maximums.** Looking at the second-law efficiency reminds us to look for other possibilities.

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*Device efficiency, not system efficiency. Second-law efficiency is always supposed to be system efficiency.

**Fuel cells can theoretically have a second-law efficiency of 100%. From as long ago as 1894, physicists have been pointing out that it would be more efficient to get electric power from fuel cells than from boilers. However, to this day no one has invented a fuel cell that will provide dependable, long-term service. A new design is being tested now.

Incidentally, second-law efficiency is not an ideal measure either. For a device to be 100% second-law efficient, it would have to work infinitely slowly. That is too long to wait. Many people are giving this subject a great deal of thought these days, and it may be that we will devise another way of describing efficiency that will be even more useful.

Homework Assignment

Assign the following problem for homework.

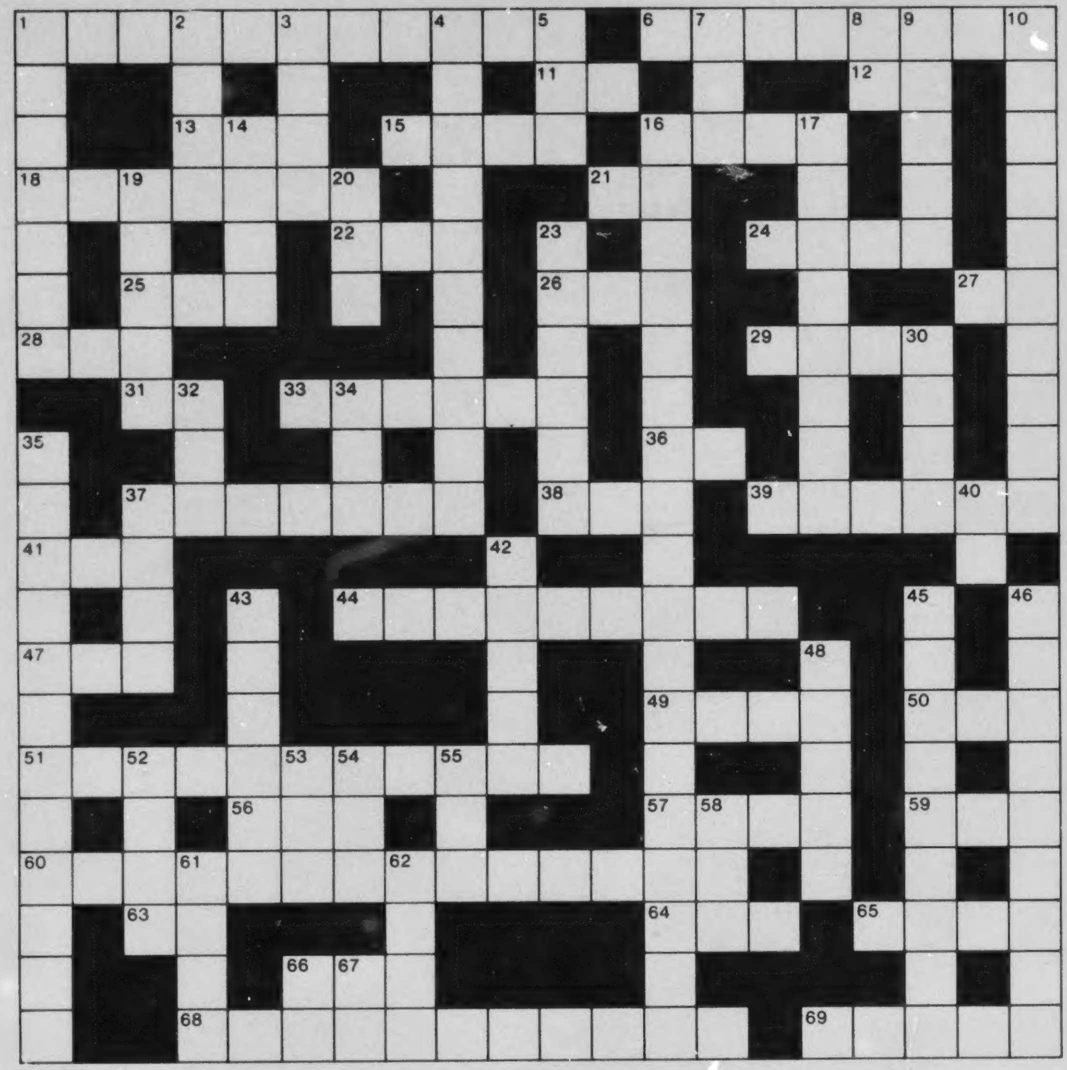
One of the things second-law efficiency points out is that things can be warmed to a low temperature more efficiently with a heat source at low temperature than with one at a high temperature. Since we are talking about people's houses, by low temperature we mean temperatures below the boiling point of water.

1. Make a list of all the uses of low-temperature heat in your home.
2. For each use, describe what kind of energy you are using to get that low-temperature heat. Is it a high-quality form of energy?
3. Is there any low-temperature heat around your home, free for the taking (and the taking is NEVER free), that you could use to replace some of the energy in question 2?

Projects for Independent Investigation

1. Interview the manager of a firm in your community that installs heat pumps. What kinds of skills are necessary to install and maintain heat pumps? Where did most of his workers get their skills?
2. Report to the class on whether heat pumps are suitable for use in your community.

crossword by Joan Kaplowitz



ACROSS
1. device for measuring temperature
6. revolving part of electric motor
11. all right
12. opposite of off
13. pronoun
15. what you do with a thermometer
16. kind of chemical energy
18. one way of storing electrical energy
21. conjunction
22. kind of tree
24. untruthful person
25. take in chemical energy
26. painters and sculptors make this
27. greeting
28. this is sensitive to sound
29. halt
31. pronoun
33. kind of energy
36. pronoun
37. unit for measuring heat
38. small child
39. what we're learning about
41. what 24 Across tells
44. device for changing light to electricity
47. moist
49. not less
50. roll
51. how fast the atoms and molecules are moving randomly
56. piece of cloth
57. what happens to some of the energy every time we do an energy conversion
59. vehicle
60. unit used to measure energy provided by engines
63. knock out (abbr.)
64. used in tennis
65. unit which measures electrical "pressure"
66. baseball ________
68. form of energy
69. device that converts other forms of energy to mechanical energy

DOWN
1. device which converts flow of fluid to motion of shaft
2. what people like to do after heavy use of musclepower
3. preposition
4. device to convert heat to electricity
5. should teachers spare this?
7. kind of grain
8. preposition
9. not above
10. how much energy we get out of a conversion in the form we want it compared to how much we put in.
14. what calories measure
16. unit for measuring heat
17. process that changes motion to heat
19. gas companies' name for 100,000 Btu
20. not no
23. French scientist who studied heat engines
30. lacking money
32. period of time
34. used with musclepower to move boat
35. unit to measure electrical energy
37. one-hundredth of a dollar
40. opposite of stay
42. contains only hydrogen and oxygen
43. unit to measure electrical current
45. natural gas is sometimes sold by this unit
46. device to change motion to electricity
48. used for chewing
52. grade
53. discuss (slang)
54. a long time ________
55. operate
58. we get metals from this
61. ________ but not all
62. unit to measure electrical power
66. verb
67. alternating current (abbr.)

1 T	H	E	2 R	M	3 O	M	E	4 T	E	5 R	■	6 A	7 R	M	A	8 T	9 U	R	10 E
U	■	■	E	■	V	■	■	H	■	11 O	K	■	Y	■	■	12 O	N	■	F
R	■	■	13 S	14 H	E	■	15 R	E	A	D	■	16 B	E	E	17 F	■	D	■	F
18 B	A	19 T	T	E	R	20 Y	■	R	■	■	21 O	R	■	■	R	■	E	■	I
I	■	H	■	A	■	22 E	L	M	■	23 C	■	I	■	24 L	I	A	R	■	C
N	■	25 E	A	T	■	S	■	O	■	26 A	R	T	■	■	C	■	■	27 H	I
28 E	A	R	■	■	■	■	■	P	■	R	■	I	■	29 S	T	O	30 P	■	E
■	■	31 M	32 E	■	33 M	34 O	T	I	O	N	■	S	■	■	I	■	O	■	N
35 K	■	■	R	■	■	A	■	L	■	O	■	36 H	E	■	O	■	O	■	C
I	■	37 C	A	L	O	R	I	E	■	38 T	O	T	■	39 E	N	E	R	40 G	Y
41 L	I	E	■	■	■	■	■	■	42 W	■	■	H	■	■	■	■	■	O	■
O	■	N	■	43 A	■	44 S	O	L	A	R	C	E	L	L	■	■	45 C	■	46 G
47 W	E	T	■	M	■	■	■	■	T	■	■	R	■	■	48 T	■	U	■	E
A	■	■	■	P	■	■	■	■	E	■	■	49 M	O	R	E	■	50 B	U	N
51 T	E	52 M	P	E	53 R	54 A	T	55 U	R	E	■	A	■	■	E	■	I	■	E
T	■	A	■	56 R	A	G	■	S	■	■	■	57 L	58 O	S	T	■	59 C	A	R
60 H	O	R	61 S	E	P	O	62 W	E	R	H	O	U	R	■	H	■	F	■	A
O	■	63 K	O	■	■	■	A	■	■	■	■	64 N	E	T	■	65 V	O	L	T
U	■	■	M	■	66 B	67 A	T	■	■	■	■	I	■	■	■	■	O	■	O
R	■	■	68 E	L	E	C	T	R	I	C	I	T	Y	■	69 M	O	T	O	R

Additional Resources

General Books on Energy

Energy, by Irving Adler. (NY: John Day, 1970.) Elementary.

Energy, by Mitchell Wilson. (NY: Silver Burdett, 1968.) A volume in the Life Science Series. Now somewhat dated in the choice of units of measurement and, to some extent, technology; but still probably the most inviting single publication on the topic.

Energy and Engines, by D.S. Halacy, Jr. (NY: World, 1967.) Out of print. Upper elementary.

Energy and Power, by Robert Irving (pseudonym of Irving Adler). (NY: Knopf, 1958.) Out of print. Upper elementary.

Energy: Power for People, by Laurence Pringle. (NY: Macmillan, 1975.) Junior high.

Fundamental Physical Forces, by Raymond A. Wohlrabe. (NY: Lippincott, 1969.) Junior high.

How Did We Find Out About Energy? by Isaac Asimov. (NY: Walker, 1975.) Out of print. Elementary.

Power and Energy, by Noemie Benczer-Koller and Earl L. Koller. (NY: Stravon, 1960.) Elementary.

More Advanced General Books

The Concept of Energy Simply Explained, by Morton Mott-Smith. (Paperback reprint, NY: Dover, 1964.) First published in 1934 as *The Story of Energy*. A very readable, nonmathematical treatment of energy. Recommended for teachers and advanced high school students.

The Conquest of Energy, by George Russell Harrision. (NY: Morrow, 1968.) Out of print. Senior high.

Energy Does Matter, by Werner Emmerich, Milton Gottlieb, Carl Helstrom, and William Stewart. (NY: Walker, 1964.) Senior high.

Energy into Power: The Story of Man and Machines, by E.G. Sterland. (NY: Natural History Press, 1967.) Out of print. Junior high.

Heat and Thermodynamics

The Concept of Heat and Its Workings Simply Explained, by Morton Mott-Smith. (Paperback edition, NY: Dover, 1962.) Originally published in 1933 as *Heat and Its Workings*.

Experiments with Heat, by Harry Sootin. (NY: W.W. Norton, 1964.) The introductions to the experiments are far superior to those provided in most such collections. For junior high and teachers.

Heat Engines, by John F. Sandfort. (NY: Anchor Doubleday, 1962.) The original edition, a paperback in the series sponsored by the PSSC, cost 95¢ and is out of print. Greenwood Press, Westport, CN, has kept it available by issuing a reprint for $20 (sic). For advanced high school students and teachers.

The Heat's On! by A. Harris Stone and Bertram M. Siegel. (Englewood Cliffs, NJ: Prentice-Hall, 1970.) Out of print.

The Nature of Thermodynamics, by P.W. Bridgman. (Paperback reprint, NY: Harper Torchbooks, TB 537.) Advanced.

Science by Degrees: Temperature from Zero to Zero, by Jack Castle, Jr., Werner Emmerich, Robert Heikes, Robert Miller, and John Rayne. (NY: Walker, 1965.) Out of print. Senior high.

The Second Law, by Henry A. Bent. (NY: Oxford University Press, 1965.) Paperback edition available. For teachers with a background in the physical sciences and advanced high school students. Parts One through Four do not require calculus. The author's skillful interweaving of analysis, historical anecdote, and concrete example makes it possible to benefit from this book even if you skip the math. For Bent's ideas on teaching the second law, see "The Second Law of Thermodynamics: Introduction for Beginners at Any Level," **Journal of Chemical Education**, Vol. 39, p. 491, 1962.

Temperatures Very High and Very Low, by Mark W. Zemansky. (NY: McGraw-Hill, 1964.) Out of print. For advanced secondary students and teachers.

Engines

Engines, by Peter R. Limburg. (NY: Franklin Watts, 1920, 88 pp.) Upper elementary.

Engines, by Paul Roberson. (NY: John Day, 1965, 48 pp.) Out of print. Elementary.

Engines and How They Work, by Geoffrey Boumphrey. (NY: Franklin Watts, 1960, 225 pp.) Out of print. Junior high.

Man and Power: The Story of Power from the Pyramids to the Atomic Age, by L. Sprague DeCamp. (Racine, WN: Golden Press, 1961, 189 pp.) Out of print.

Motors and Engines and How They Work, by Harvey Weiss. (NY: Crowell, 1969, 64 pp.)

Electricity and Magnetism

Experiments with Electric Currents, by Harry Sootin. (NY: W.W. Norton, 1969, 88 pp.) Junior high.

Experiments with Static Electricity, by Harry Sootin. (NY: W.W. Norton, 1969, 86 pp.) Junior high.

First Electrical Book for Boys, 3rd Edition, by Alfred Morgan. (NY: Scribners, 1963.) Though now dated, the books of Alfred Morgan were for many years the staple introduction to "hands-on" science and technology for young people, as many middle-aged teachers can attest. We list them in a tribute to the nostalgia craze; but they still have some distinctive virtues.

Lightning in Harness: Foundations of Electricity, by Leslie Baseford and Joan Pick. Published, 1966, by Sampson Low, Marston and Co., Great Britain. Distributed in the U.S. by Ginn, Boston, MA (127 pp.). Junior high.

Magnets: The Education of a Physicist, by Francis Bitter. (NY: Doubleday, 1959.) Senior high.

Turned On: A Look at Electricity, by A. Harris Stone and Bertram M. Seigel. (Englewood Cliffs, NJ: Prentice-Hall, 1970, 64 pp.) Junior high.

Mechanics

Moving Right Along: A Book of Science Experiments and Puzzles About Motion, by Robert Gardiner and David Webster. (Garden City, NY: Doubleday, 1978.) For junior high on, and the teacher.

Perpetual Motion

Perpetual Motion: The History of an Obsession, by Arthur W.J.G. Ord-Hume. (NY: St. Martins, 1977.) Senior high.

Efficiency (from a theoretical point of view)

Efficient Use of Energy, Part I, A Physics Perspective, by K.W. Ford, G.I. Rochlin, and R.H. Socolow; Principal Investigators, Marc Ross and R.H. Socolow. (NY: American Institute of Physics, 1975.) For the teacher with a background in the physical sciences. The work that introduced the concept of second-law efficiency. Tutorial.

Experimentation and Measurement

Experimentation and Measurement, by W. J. Youden. (NY: Scholastic Book Services, 1962.) Out of print.

For Good Measure, the Story of Modern Measurement, by Melvin Berger. (NY: McGraw-Hill, 1969.) Out of print.

Invitations to Investigate: An Introduction to Scientific Exploration, by Paul F. Brandwein and Hy Ruchlis. (NY: Harcourt Brace Jovanovich, 1970.)

A Question of Accuracy, by Arthur G. Razzel and K.G.O. Watts. (NY: Doubleday, 1964, 46 pp.) Out of print. Elementary.

Notes

CONSUMABLE ITEMS	PRICE	ALTERNATIVES	HAVE ?	DEM	GRP	30 IND	EXTENSION
acetate sheets	10/8.40			1	NA	NA	
aluminum foil, regular	75′/1.31	none		1	1	1	
aluminum sheet	sq. ft./free	from frozen pie pans, TV dinner trays, etc.		2	4	4	
battery, 9 volt, (Eveready 716 or Burgess 4F6H)	11.94	bank of #6 cells; isolated power supply		1	7	15	
bills, utility	free	none		2	NA	NA	
bleach, household	2 qts./.70	none		1	1	1	
candle	4/1.00	Sterno, bunsen burner, varies with activity		1	3	7	
can, metal (tin)	free	none		1	15	30	
cardboard, corrugated	free	wood		X	X	X	
cartons, half gallon milk	free	none		2	30	30	
cup, styrofoam	50/.70			1	1	NA	
dropper, medicine	144/11.00	glass tube drawn by students		1	1	1	
dry cell, 1½ volt #6	3.85	AC power supply; 9 volt battery		6	12	30	
film can, plastic	free			1	1	NA	
ice cubes	trayful/free	none		1	2	3	
jar lid, plastic	free			1	1	NA	
jars, small baby food	free	aerosol can closures; medicine cups		1	15	30	
light, fluorescent	12.00-20.00	see lesson plan		1	NA	NA	
modeling clay	1b./1.20	varies with lesson; eg test tube racks		1	NA	NA	
nail, small	pkg./.85	thumb tacks		1	1	NA	
nails, 16-d common	box/1.09	iron bar		1	1	1	
nuts, #8 steel	12/.69			1	1	NA	
paper towels	roll/.70	none		1	1	1	
paraffin	lb./1.00	photographer's light meter		1	1	1	
rubber bands #84	¼ lb./1.80			1	1	NA	
salt	lb./.30	none		1	1	1	
sand	lb./free			1	1	NA	
sandpaper, silicon carbide	sheet/.79			1	1	1	
screening, window	1′x2′ for $2.00			1	1	NA	
silicone glue-sealer	tube/3.20	no substitute		1	5	5	

CONSUMABLE ITEMS	PRICE	ALTERNATIVES	HAVE ?	DEM	GRP	30 IND	EXTENSION
string	120 ft./.79						
tape, masking	42 yds./.99	none		1	5	10	
tape, vinyl electrical	44′/2.00	none		1	2	15	
wire, coat hanger	free			5	20	60	
wire, copper bell wire	ft./.06	magnet wire					
wire, copper zip cord 16 gauge	ft./.29	none		1	3	5	
wire, copper, #28 magnet	lb./7.35	none		1	2	2	
wire, iron, 18 gauge	50′/.80	very coarse picture hanging wire; coat hanger		1	1	1	
wire, picture hanging	25 ft./.80	none		1	1	1	
wire, solid copper, 18 gauge	ft./1.00			5		90	
wire, solid copper, 12 gauge	ft./.12	none		1	NA	NA	
wood, board 1"x4"x12	.25			1	10	30	
DURABLE ITEMS							
ball, hard rubber	.41			1	1	NA	
BB's	pkg. 1500/1.50	lead shot; split shot sinkers		1	1	NA	
beaker, 400 mL	12/13.50	pint jar, measuring cups		1	12	NA	
bicycle		borrow for one day		1	1	NA	
bit, ⅜ inch, wood	2.69			1	1	NA	
bottles, plastic gallon	free			1	5	NA	
bricks	.27	any weight		4	40	NA	
bulb, clear incandescent	1.10	none		1	NA	NA	
bulb, intermediate base, clear (4076½/2)	2.50	12-volt auto bulbs; elec. calorimeter		1	1	NA	
cap, ¾", copper	.70			1	1	1	
circuit breaker	free	scavenge broken one		1	NA	NA	
clock, sweep second hand	16.00	wristwatches, stop watches		1	1	1	
clockwork toy		borrow one for day		1	NA	NA	
compass	1.00	galvanometers		1	10	30	
container, plastic pint	free	glass jars		1	1	NA	
container, plastic quart	free	glass jars, beakers		1	15	30	

DURABLE ITEMS	PRICE	ALTERNATIVES	HAVE ?	DEM	GRP	30 IND	EXTENSION
cord, extension	12 ft./3.33	lamp cord and plug		1	NA	NA	
corks	100/3.50			1	1	1	
dimmer	7.95	autotransformer or rheostat from physics lab		1	NA	NA	
filter, infrared	4.95			1	NA	NA	
fuses	4/1.25	need some that burned out		1	NA	NA	
graduated cylinder, 100 mL	2/6.12	graduate your own bottles; measuring cups		1	5	15	
hand drill	10.00	borrow from school shop		1	3	NA	
heat pump ads and brochures	free	none		X	NA	NA	
hot plate, electric	14.00	none		1	5	NA	
iron filings	lb./2.20	none		1	1	NA	
knife, utility	4.00	saw		1	10	10	
light, fluorescent	13.00–25.00			1	1	NA	
magnets, alnico bar	pair/7.50	chrome steel bar magnets; magnetized iron bars		1	10	30	
meter, photographers light		borrow or use paraffin photometer		1	NA	NA	
meterstick	2.05	none		1	15	30	
motor, miniature electric	.29–2.95	none		10	10	30	
nail, 40-d common	.07	none		2	2	NA	
pail, plastic	6 qt./2.37	sink in classroom		1	NA	NA	
pans, 2 liter capacity	2.70–17.00	borrow for the one day needed		1	10	NA	
pipe, ¾ inch plastic	10′/.90			4	10	NA	
pliers, gas pattern	2.60–6.00	use bare hands		1	12	25	
projector, overhead	$$$	optional		1	NA	NA	
radiometer, Crookes	5.00	none		1	NA	NA	
roller skates, clamp on	pr./5.88	carts, e.g. Eduquip		1	7	15	
ruler	.19	none		5	10	30	
socket for light bulb	1.45			2	NA	NA	
socket, intermediate lamp, such as Leviton #199	1.29	see lesson plan		1	NA	NA	
socket, miniature lamp	.60	LED + resistor; compass + coil		NA	12	30	
solar cell	10.00	none		1	5	NA	
spring balance, 0-20 N	3.25			1	10	NA	

DURABLE ITEMS	PRICE	ALTERNATIVES	HAVE ?	DEM	GRP	30 IND	EXTENSION
support, such as ring stand	8.00			1	NA	NA	
test tubes, 20mm	72/17.50	olive jars, in many cases		1	1	1	
thermometers, Celsius	.95–4.50	essential for all students		30	30	30	
tubes, cardboard	free	from paper towels, toilet paper		1	15	15	
tubing, plastic, ⅛" ID	ft./.15–.25			1	NA	NA	
vacuum bottle	7.50	see lesson plan		1	7	NA	
wood, boards-nominal 1"x13"	running ft./.75			3	20	NA	
yardstick	1.99			1	NA	NA	

Unit Two
Energy Flows in Nature

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Narrative Overview

Why We're Teaching This

The lessons in Unit One teach that using energy always involves changing it from one form to another. Students were introduced to the idea of energy flow: we cannot create energy, and in the course of changing from one form to another energy eventually ends up as heat.

Energy flow is a powerful concept with important applications in all the sciences, as well as in energy conservation. However, in Unit One students encountered it only in a limited context, mostly familiar household energy conversions.

In Unit Two students will become more familiar with the concept of energy flow by applying it on a much grander scale. Our vision opens to the "big blue marble" in space: the energy budget of planet earth. Almost all of the energy on earth originates in light from the sun; almost every change on earth is part of an energy flow from the sun. Learning to apply the idea of energy flow to weather, life, and geological processes greatly enriches students' understanding and appreciation of the changes they see in the world around them, and reinforces their understanding of energy.

What We'll Teach and How

The sun's energy reaches us in the form of radiation. This radiation heats the atmosphere and the land and water of the earth's surface. Teacher demonstrations relate the heating power of sunlight to the wind and water cycles. The changes we see as weather are due to one way flows of heat, but materials, like air and water, are recycled.

Life also depends on an energy flow from the sun. The text and teacher give the students an elementary description of photosynthesis. In activities, students test the description by attempting to detect oxygen released by a plant in sunlight, and by correlating starch in leaves with light striking the leaves. Making a calorimeter, students measure the energy stored in foods.

The release of food energy through respiration is investigated in activities in which students seek the predicted products, carbon dioxide and heat, in plants as well as animals. Students correlate their rate of carbon dioxide production with their rate of exertion. The two processes, photosynthesis and respiration, are seen as complements which make a cycle like the wind and water cycles: materials (carbon, hydrogen, and oxygen atoms) are recycled, while energy flows through in one direction.

Energy also flows through communities of living things, from green plants to predators. Only a sampling of this topic is included in this edition.

Studying the energy inputs to the United States food system is a good follow-up to food chains, even though this is not an "energy flow in nature." Otherwise, some students may not realize the extent to which their food supply is dependent on energy inputs other than sunlight.

Finally, we consider how energy has been stored in the earth through geological processes. These lessons provide the transition to the next unit on the history and technology of the fossil fuels.

Coming Attractions

As was mentioned earlier, the next edition of **Energy** 80 will include additional lesson plans filling out more thoroughly the sequence of ideas presented above. In particular, you can expect additional material on:

- Adaptation of plant structure to carrying on photosynthesis: flow of water, flow of gases, exposure of leaf surfaces to sunlight.
- Food webs: including simulations of energy flow in two communities
- The U.S. food system
- Biological aspects of the origin of fossil fuels: including looking for fossils in coal

Users of the last edition will notice improvements in many activities. Many of these revisions came from suggestions by your fellow teachers—maybe from you. We wish to continue to make **Energy 80** more meaningful to students and more useful to you, but we need your help to do so. Mark up a page and mail it to us. Send students' comments. Phone and let us know what has worked for you, what hasn't worked, what you want to see in the future. But let us hear from you. Thanks.

Wind Cycles

Objectives

This lesson contributes to developing the students' understanding of the following concepts:

The energy of winds and storms comes from the sun.

Unequal heating of different parts of the earth is the fundamental cause of winds.

Format of the Lesson

Convection currents demonstration

Wind cycle box demonstration

Land and sea breezes

Materials Needed

candle

spinner made of a throw-away aluminum tart pan. (Note that we aren't throwing it away.) With a needle, punch three equally-spaced holes in the rim. Suspend the pan upside down from a single thread by running a thread through each of the three holes, and knotting them together with a fourth thread. With scissors, cut radial slots up to about 2 cm from center of the pan. Twist the resulting vanes, all in the same direction.

swivel preferably ball-bearing, such as Sampo number 3SB, three for $2.50 at sporting goods stores. Less expensive barrel swivels can also be used.

balloon (optional) If you choose to do this activity, you need two fairly large balloons, preferably dark-colored. Blow them up and tie them with string, hang them about 10 cm below the ends of a bar about a meter long. A good kind of bar to use is a one-eighth-inch metal bar, available at hardware stores for about 80¢. File a notch 1 cm from each end to which to tie the balloons; file a flat in the middle. Balance the bar on a single-edged razor blade stuck edge up in a piece of cork or beadboard. If you put the cork on the corner of a table, the balloons can hang down without touching the table leg. You will also need a heat lamp to heat one of the balloons. See the drawing on the next page.

overhead transparency **Land and Sea Breezes.** Make from master at the end of this lesson; you may want to have it colored with felt pens.

cardboard box about 30 cm by 30 cm by 60 cm. Dimensions are not critical.

cardboard tubes like those that come in the middle of rolls of paper towel. Should be about 30 cm long.

saw for cardboard

aluminum foil

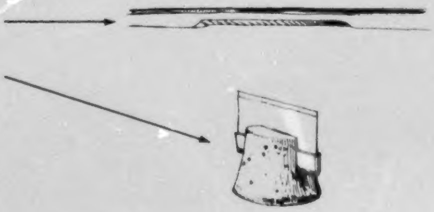
black construction paper or black paint. Poster paint will do, or (if for teacher use) a can of black spray paint.

masking tape

plastic wrap

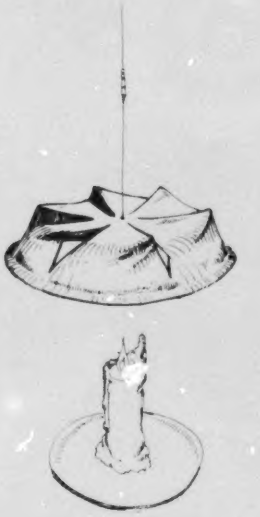
fine strips of tissue

a sunny day or at worst an intense incandescent light source.



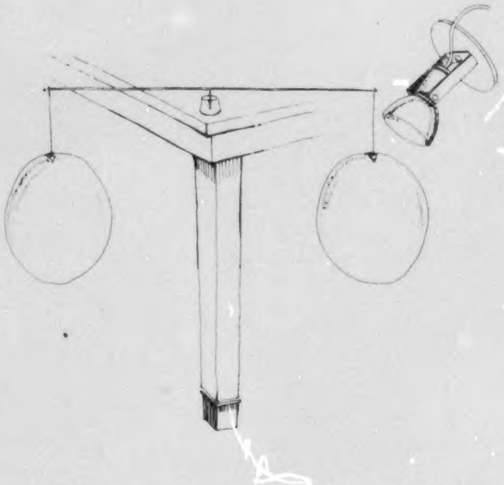
Convection Currents

Light a candle and suspend the spinner above it. (Alternatively, and more fun, you may have one of those Scandanavian Christmas decorations in which hot air rising from candles causes brass angels to revolve and strike bells.) Ask students were the energy to make the spinner turn is coming from (ANS: Chemical energy in the candle, to heat energy, to motion of the spinner.)



What causes the spinner to turn? Some student will probably respond that hot air rises and that turns the spinner. This is correct and you may wish to leave it at that. (The spinner is really a kind of turbine, converting a linear flow of fluid into rotation of a shaft.) Or, you may wish to extend the discussion into convection currents and buoyancy.

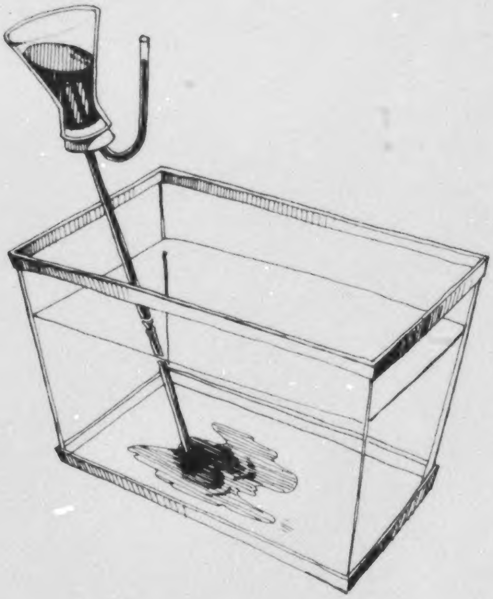
A good demonstration of the buoyancy of warm air is the balloon balance. Adjust the balance until the two balloons just exactly balance. Then heat one of the balloons with a lamp (from the side, because putting the lamp directly beneath the balloon creates an air current that could push the balloon up). The balloon will increase in size, and at the same time the scale will become unbalanced, with the heated balloon rising.



We have the same number of molecules in the balloon as before, but now they take up more space. So the air in the balloon is less dense than it was, since density is a comparison between mass and volume. Less dense fluids float to the top of denser fluids, in this case the colder the air in the room.

For your own information, note that in our experiment air pressure was kept relatively constant, because the balloon resists expansion fairly weakly. When the difference between the pressure inside and outside the balloon get too great, the balloon compensates by expanding. In the atmosphere, however, differences in heating by solar radiation are transformed into differences in air pressure.

To show convection currents created by temperature differences, and to demonstrate that "hot air rises" doesn't just apply to air, set up an aquarium full of cold water. Use a glass tube to inject a slug of hot water colored with dye into the bottom of the aquarium, as shown in the drawing. What happens to the hot water?



Conclude that a difference in temperature could create movement in nature just as it does in a heat engine.

Demonstration of the Wind Cycle Box

You may choose to have this apparatus assembled in advance by students, or you may want students to build it as a class activity. Construction directions are given on the activity sheet. Following the investigation, discuss the questions at the end of the activity sheet. Conclude that light energy can lead to heat which then can cause a movement of air.

Sea Breezes

Review the results of the activity in which we discovered that jars of air, water, and soil, warmed by the sun, did not change temperature at the same rates.

Put on the overhead transparency of land and sea breezes. Ask the students which will warm up faster after sunrise, the land or the sea? Which will be warmer by noon? Mark the transparency to show the hot air rising over the land and the cooler air coming in from the sea.

What will the situation be at night, after the sun goes down? The ocean will hold its heat better than the land. Now warm air will be rising over the ocean and air cooled by contact with the land will flow toward the sea. The land breeze is much weaker than the sea breeze, however.

With many additional complications, this is basically what causes all winds.

Projects for Independent Investigation

1. If the poles (North and South) are the coldest parts of the earth and the equator the warmest, why do the winds in our country mostly blow from west to east, instead of from north to south? Investigate the Coriolis Effect and write a report on it.
2. What causes currents in the ocean like the Gulf Stream?
3. Is the way you fly a hot-air balloon affected by how sunny the weather is and, if so, how?

A Box of Wind

In this investigation, we will try to see whether light energy can cause air to flow. To make the apparatus, you will need:

☐ a cardboard box

☐ aluminum foil

☐ black construction paper or black poster paint

☐ two cardboard tubes

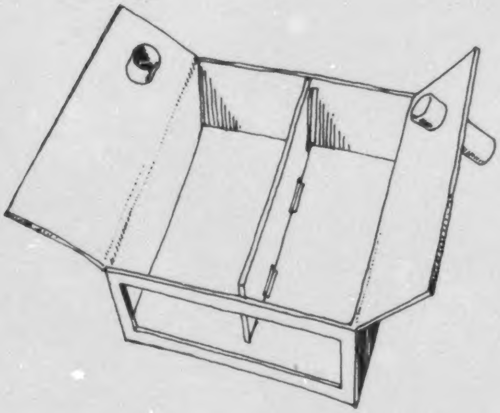
☐ tape

☐ plastic wrap

☐ fine strips of tissue

Do you have everything you need?

Procedure



Step One: Cut a window that takes up most of one long side of the box (not the top or bottom).

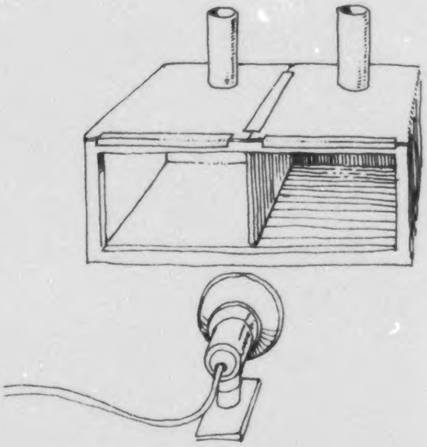
Step Two: Cut a piece of cardboard to fit inside the box. It should be just as high as the box is high, and about 5 cm shorter than the width of the box. You can probably use one of the box flaps for this. Tape this piece of cardboard into the box, dividing the box in half. Leave the 5-cm gap on the side in which you cut the window.

Step Three: Line half the box with aluminum foil. Line the other half with black construction paper, or paint it black.

Step Four: Cut two holes big enough to fit the cardboard tubes. The holes should be on top of the box, one on each side, and very near the side of the box opposite the window. Put the tubes in the holes, leaving as little tube sticking in the box as possible. Tape the tubes in place, sealing the hole with tape.

Step Five: Cover the window with plastic wrap, taping it in place.

Step Six: Let the sun or a very strong light shine on the window side of the box. After a few minutes, hold pieces of fine tissue near the tops of the tubes.



Questions to Answer on a Separate Piece of Paper

1. Is air moving in the tubes? Which way?
2. Which side of the box do you think is hotter? Why?

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The Water Cycle

Note: The two demonstrations in this lesson can only be done on a bright sunny day.

Objectives

This lesson contributes to students' understanding of the following concepts:

Heat produced by the absorption of sunlight promotes the evaporation of water.

A temperature difference can be used to produce motion.

Water goes round and round in the water cycle and is not used up.

The water cycle is driven by energy from the sun.

Through hydroelectric plants, we get electrical energy from the water cycle.

Format of the Lesson

(Prepare waterwheel in advance)

Discuss and demonstrate evaporation

Distribute observation sheets

Take class outside

Demonstrate water-cycle jar

Allow students time to complete observation sheet

Briefly discuss hydroelectric power

Materials Needed

dishes two, preferably dark colored

glass jar one gallon. $1 at supermarkets. Though the trend is to plastic, these can sometimes be salvaged from cafeterias or restaurants. The jar **must** be clear.

aluminum foil heavy-duty, about one square foot.

wire coat hanger or similiar gauge.

tape such as Scotch® transparent tape.

ruler

ice cubes about one tray-full.

water

black construction paper one sheet. Cut a circle from this paper just big enough to fit in the bottom of the gallon jar.

corrugated cardboard beadboard, or any other insulator big enough to rest the jar on it.

worksheets **Observing a Water Cycle Jar,** one per student

overhead transparency **The Water Cycle**

Building the Waterwheel

We suggest that you or a student build and test the waterwheel prior to class. To enable a student to do it, directions are provided on a separate activity sheet.

Evaporation

Put out two shallow dishes of water, one in a sunny location and one in the shade. Mark the water level on each. Be sure the two locations have comparable windiness.

Ask students to predict what will happen.

Ask which will get warmer, the water in the sun or the water in the shade?

After the water has evaporated, ask what happened to it? Define the word evaporated: water molecules escaped from the surface of the water into the air above. There they are invisible water vapor. The chances of a molecule's escaping depend on its speed; the faster it goes the better the chance of escaping. An increase in temperature means an increase in the average speed of the random motion of the molecules. The higher the temperature of liquid water, the more molecules will be moving fast enough to escape. In this way, sunlight promotes evaporation by heating water on the earth's surface.

Can the molecules of water vapor ever become liquid water again? Yes. They will condense when the air gets colder. Clouds are made of tiny droplets of condensed water.

Demonstrating the Water-Cycle Jar

Tell the class we are going to see how evaporation and condensation, working together, can create an energy flow.

Pass out the observation sheets.

Take the class outside, into direct sunlight.

Place the gallon jar in full sunshine on top of a sheet of insulating material, such as corrugated cardboard, beadboard, or even a folded newspaper.

Put the circle of black paper inside the jar, on the bottom.

Pour in water to a depth of 3 cm.

Insert the waterwheel. Position it so that one side of the wheel is exactly in the center of the bottle.

Cap the bottle with the aluminum foil cone (or a metal funnel plugged with a stopper). Fold the foil edges over the bottle neck, not too tightly, because you may wish to adjust the cone later to get the drip line directly over the waterwheel.

Fill the cone with ice cubes.

Cover the top of the cone loosely with a small piece of foil with a sheet of paper under it, just big enough to shield it from the sun.

Give each student a chance to observe what happens. It may be several minutes before there will be enough meltwater in the cone to cool the entire surface of the cone evenly.

Complete answers to questions while the jar can be observed. Return to the classroom.

After the Demonstration

Discuss the questions on the worksheet. Try to develop an understanding of the constancy of the amount of material, the energy flow involved (light → heat → motion), and the processes of evaporation and condensation.

Put on the overhead transparency. (You can make this more attractive by having a student color it with permanent felt tip pens.) Compare what happened in the jar with what happens on earth.

Projects for Independent Investigation

1. Choose one of the big hydroelectric dams in the United States. Find out when it was built, who built it, and what the electricity produced is now used for. Report to the class.

2. Write a description of a violent storm you have experienced.

3. What causes the dew on grass or cars early in the morning?

Making a Waterwheel

To do this, you will need:

ruler

scissors

drinking straw

heavy aluminum foil

coat hanger wire

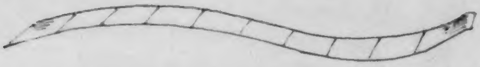
tape

Do you have everything you need?

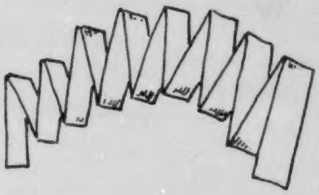
Procedure

Step One: Cut a strip of heavy-duty aluminum foil 30 centimeters long and 1 centimeter wide.

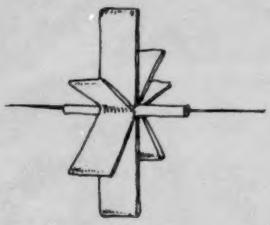
Step Two: Mark this strip into 2.5-cm sections.



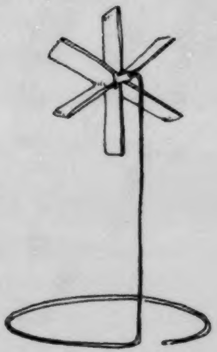
Step Three: Fold the strip into a zigzag pattern at each of the 2.5-cm marks.



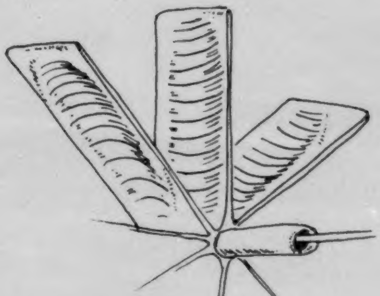
Step Four: Form the zigzag pattern into a circle. Tape the sections together as shown in the diagram, with a piece of drinking straw in the center. The straw is the bearing.



Step Five: From a coat hanger wire, make the axle and base as shown in the drawing. The upright of the base should be about 6 cm high.



Step Six: With thumb and forefinger, shape the end of each segment of the wheel so it forms a little cup to catch the falling water.



Observing the Water-Cycle Jar

On a separate sheet of paper, answer these questions:

1. Describe how the foil cone looked before we put in the ice cubes. How did it look after five minutes?

2. Where did the water dripping from the foil come from?

3. Was there more water in the jar at the beginning of the investigation or at the end?

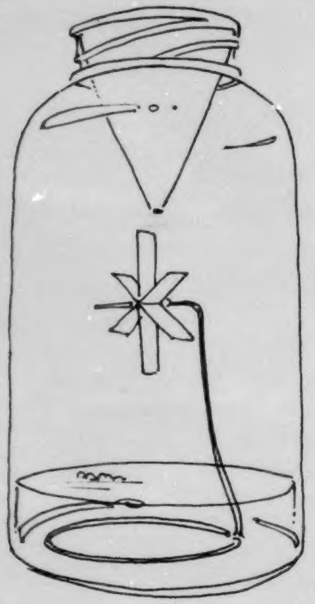
4. What do you think would happen if we had left the top of the jar open?

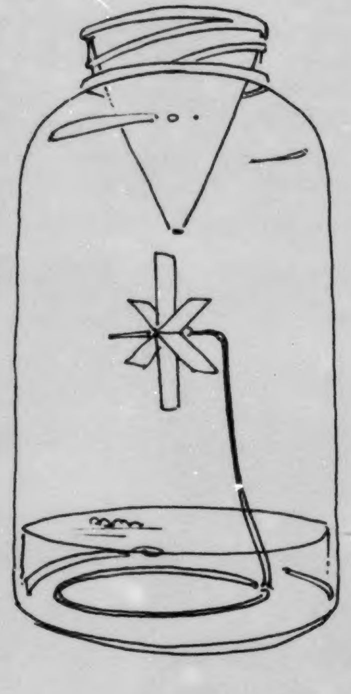
5. Why did it take several minutes before the waterwheel started turning?

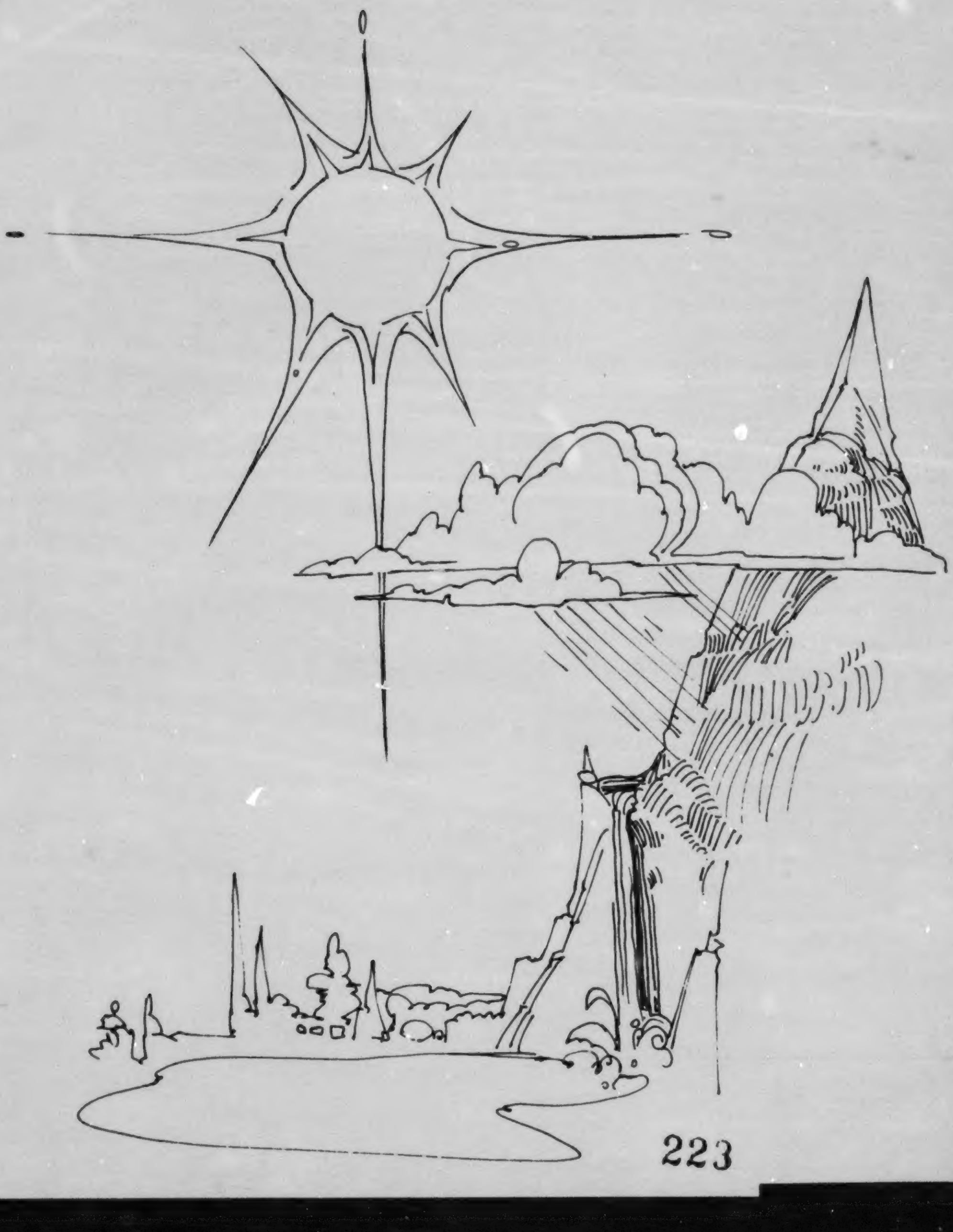
6. Where did the mechanical energy turning the waterwheel come from? Make a diagram with arrows.

7. Suppose we had filled the cone with boiling water instead of ice cubes. What do you think would have happened?

8. (Optional) Show that the water-cycle jar is a heat engine, just like a steam engine, steam turbine, or gasoline engine.







Solar Radiation Diagrams

Sunshine

We will call the amount of energy that reaches the outside of the earth's atmosphere from the sun, 100 units. That way we can show the relative size of the various energy flows. The numbers shown are informed estimates.

Much of the sunlight is reflected back into space by clouds or the earth's surface. The scattering of light by air (which is what makes the sky blue) also results in some light being directed back into space. Less than half is absorbed at the earth's surface. The atmosphere also absorbs some light.

Earthshine

Any object at a temperature above absolute zero (-273^0 Celsius) emits radiation Having absorbed light from the sun, the earth's surface is warmer than absolute zero and so it emits radiation, far-infrared radiation that our eyes cannot detect. Some of this radiation is absorbed by the atmosphere and some escapes into space. The atmosphere is also warmer than absolute zero, so it also emits radiation, some of which is absorbed at the earth's surface, and some of which escapes into space.

Wind and Water

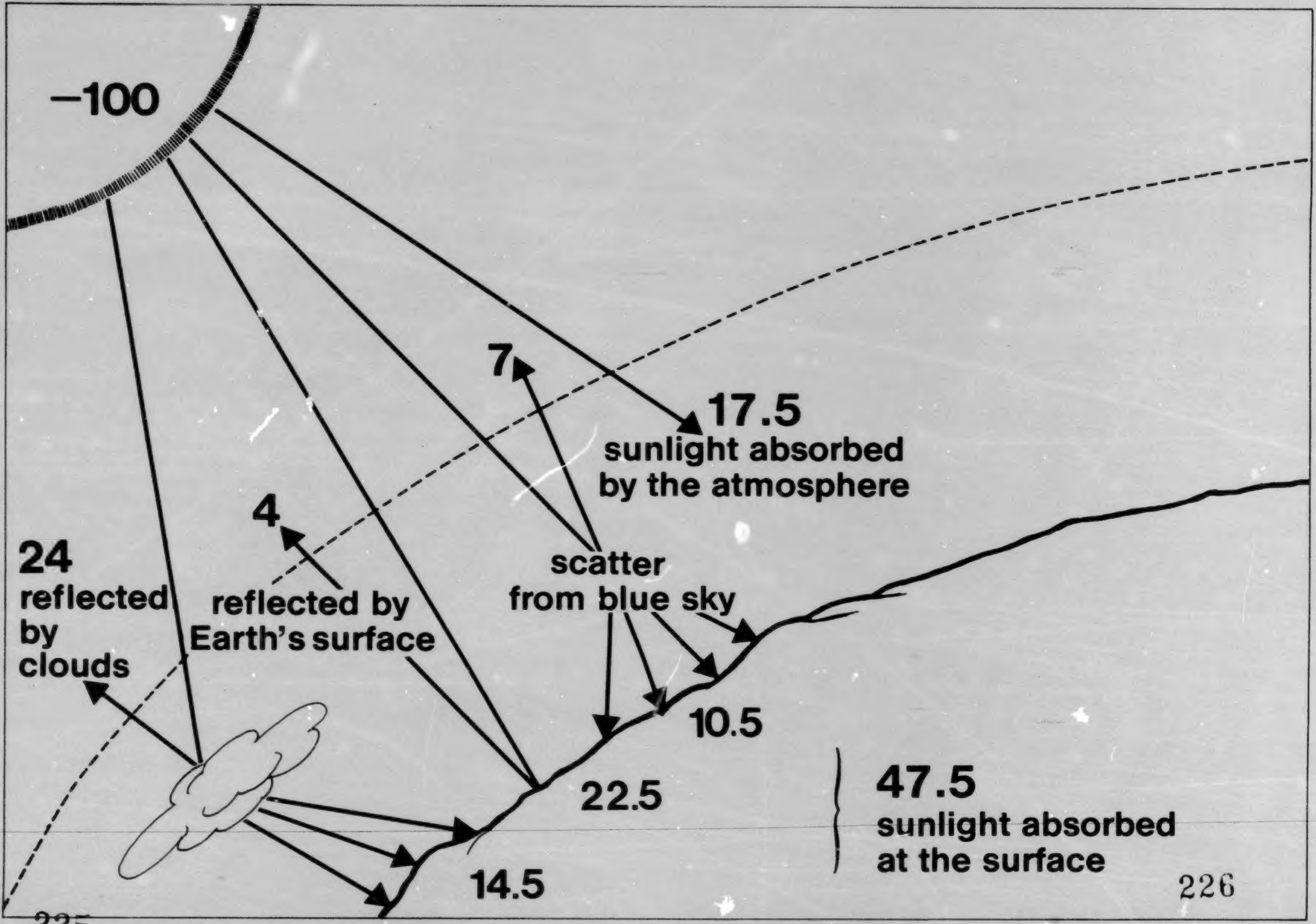
Energy is transferred from the earth's surface into the atmosphere in two ways. Air can be heated by contact with the surface. Second, energy is absorbed when water evaporates ("latent heat of evaporation"); this energy is released as heat when the water condenses ("latent heat of condensation").

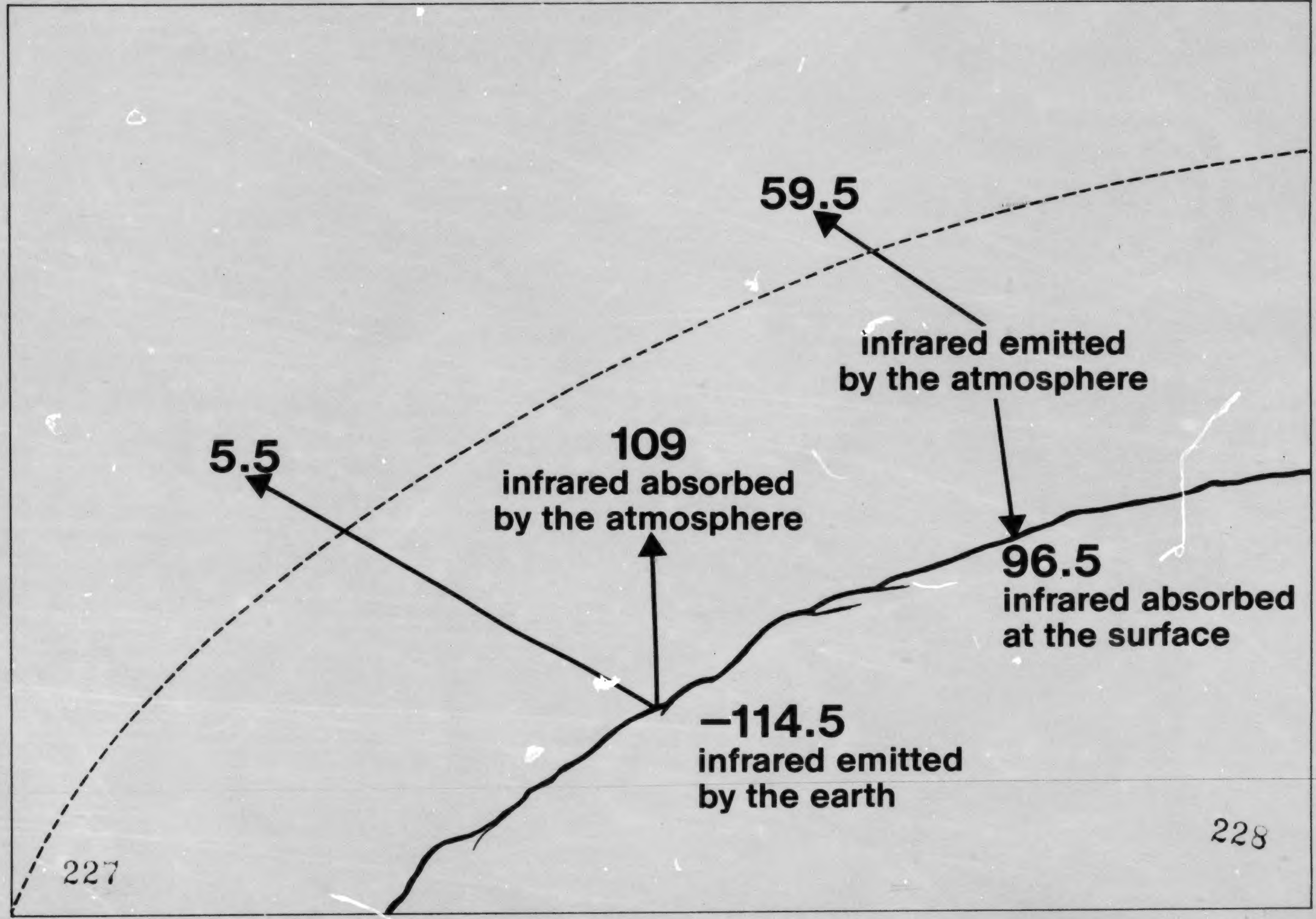
Notice how small the amount of energy captured by photosynthesis is compared to the other flows. Yet almost all life on the planet depends on this tiny fraction (0.0023%) of the total input of sunlight.

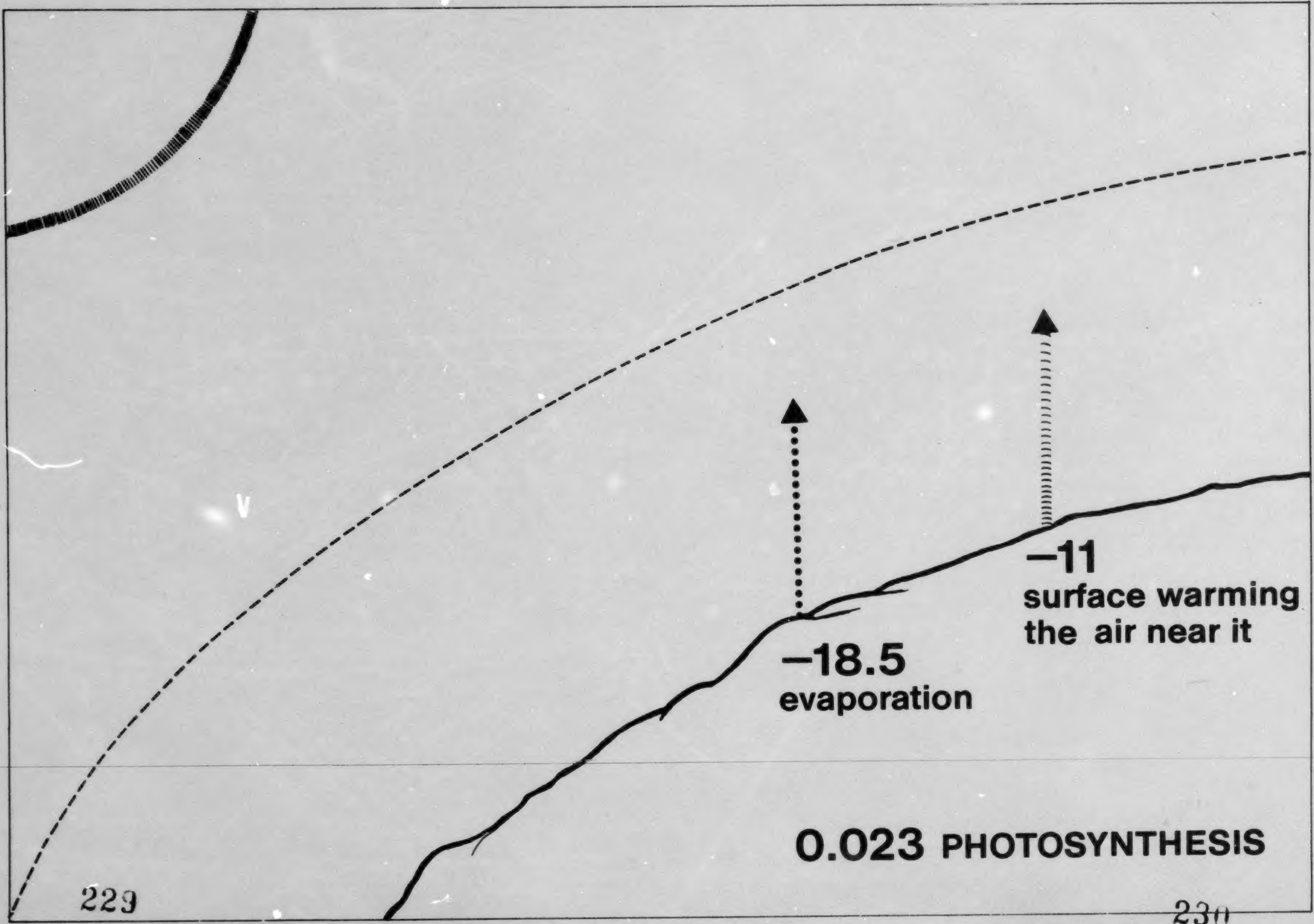
All Together Now

Total the figures for the energy escaping into space. It adds up to 100. The system is in balance; just as much energy escapes as enters. (To reveal the tiny amount put into long-term storage as fossil fuels, the numbers would have to have many more significant figures.)

SUNSHINE


—100
7
17.5
sunlight absorbed
by the atmosphere
4
24
reflected
by
clouds
reflected by
Earth's surface
scatter
from blue sky
10.5
22.5
14.5
47.5
sunlight absorbed
at the surface


59.5
infrared emitted by the atmosphere
5.5
109
infrared absorbed by the atmosphere
96.5
infrared absorbed at the surface
−114.5
infrared emitted by the earth

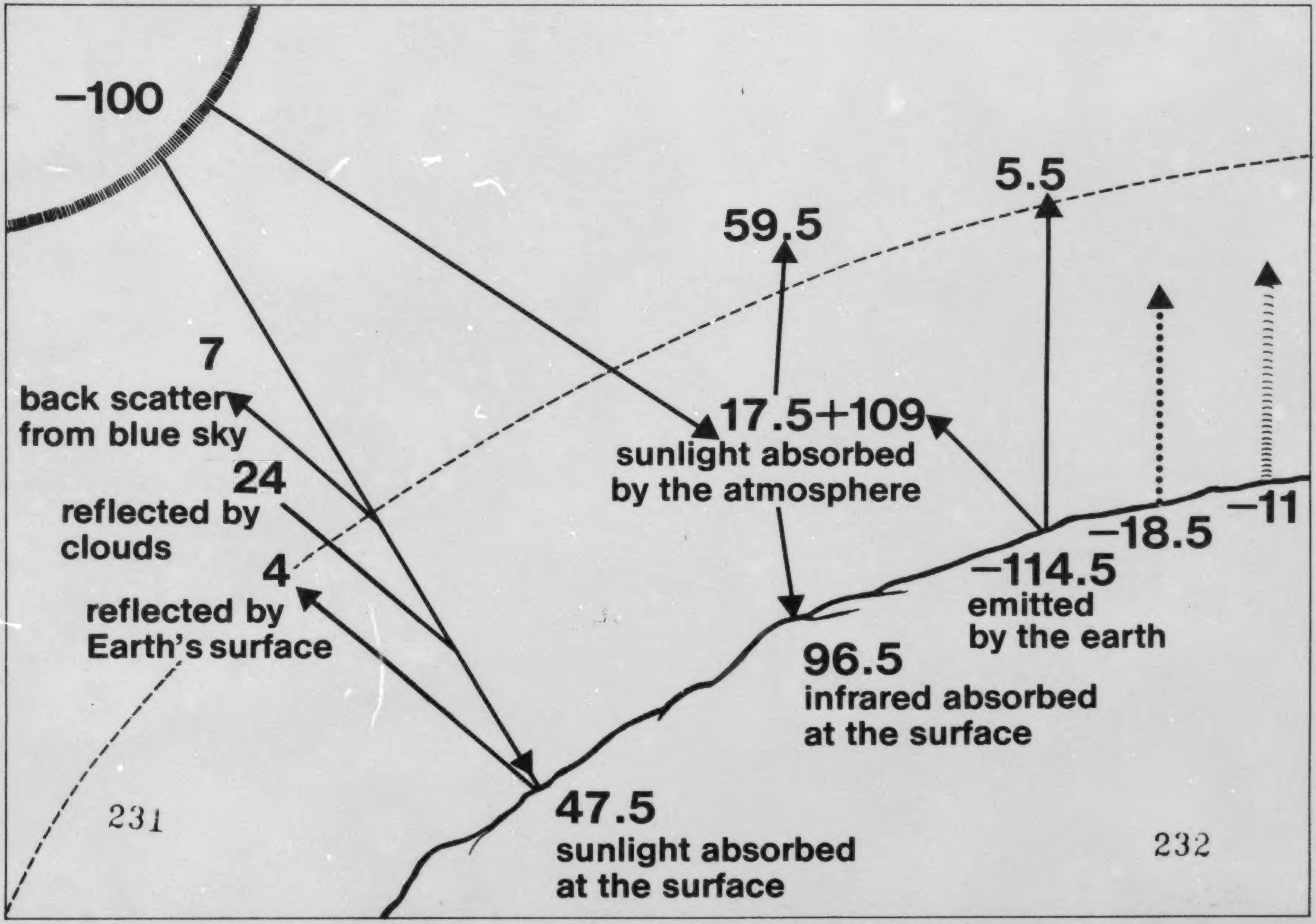


−18.5
evaporation

−11
surface warming
the air near it

0.023 PHOTOSYNTHESIS

ALL TOGETHER


−100
7
back scatter
from blue sky
24
reflected by
clouds
4
reflected by
Earth's surface
47.5
sunlight absorbed
at the surface
59.5
17.5+109
sunlight absorbed
by the atmosphere
96.5
infrared absorbed
at the surface
5.5
−114.5
emitted
by the earth
−18.5
−11

Detecting Chlorophyll

Objectives

This lesson introduces a technique chemists use to isolate one substance from a mixture of many similiar substances, and the uses that technique to indicate that all plants depend on the same green catalyst. The fundamental concept supported is:

Almost all plants depend on the same substances, chlorophyll, and the same process, photosynthesis, to convert light energy from the sun into chemical energy.

Format of the Lesson

Discuss difficulty of identifying substances

Perform student investigation

Discuss paper chromatography

Perform teacher demonstration

Materials Needed

(for the students' chromatography)

filter paper such as Whatman No. 1 or blotting paper, enough to yield one piece about 1 cm wide and as long as the tube or jar for each student or group. Filter paper discs are too small; you need the sheets.

black marking pen, water base one for every three or four groups or students. It is important that you try out the pen you plan to use before attempting this exercise with the class. The inks made by different manufacturers vary considerably in composition (as chromatography will show). Because manufacturers sometimes change the makeup of the product without changing the label, we cannot make a foolproof recommendation of a brand. Buy one and try it before you buy half a dozen.

test tube and cork or long narrow olive jar with lid

water

scissors

small paper clips (for the teacher demonstration)

spinach or geranium leaves

coarse wet-or-dry sandpaper two pieces

Ditto® fluid a small amount

jar like a small baby food jar

toothpicks three or four

filter paper or blotting paper

test tube with cork or long narrow olive jar with lid

small paper clip

Preliminary Discussion

Discuss the fact that the world is full of a number of very simple chemicals, like water, but also many very complicated substances, like chlorophyll. Frequently these substances are found mixed with other similiar substances. To identify particular substances in a mixture, chemists have had to develop many special means of comparing different substances. Today we're going to try out one of those techniques.

Distribute the worksheets.

Student Chromatography

Tell the students we will analyze marking pen ink. Ink has nothing to do with photosynthesis, it is just an easier substance to investigate.

Distribute materials. While doing this, you may want to tell students the names used for these materials in this technique. The filter paper is called the absorbant. The water is called the solvent or developer.

Post-Activity Discussion

Discuss the questions at the end of the activity sheet. Summarize that paper chromatography is a useful technique for separating some mixtures of complex substances.

Teacher Background

The pigments in the leaf of a plant are a complex mixture, and chromatography is a useful way to analyze them.

Because warm alcohol is needed to extract the pigments, this activity is probably best done as a teacher demonstration. However, you may wish to distribute the activity sheet to help students follow the demonstration.

Post-Activity Discussion

Ask students to describe the chromatogram, which can be passed around. You will probably find four distinct pigments:

carotenes, which are orange-red

xanthophylls, which are pale-yellow

chlorophyll a, which is blue-green

chlorophyll b, which is yellow-green

(A gray front indicated you kept the extract too long; it is decomposition products of chlorophyll.)

Explain that through studies like this, it has been discovered that almost all plants depend on chlorophyll to convert light energy to chemical energy, whatever the apparent color of the leaf.

Projects for Independent Investigation

1. Try other water-based inks, especially colored ones like green, and compare their components.
2. Paper chromatography is only one of several different kinds of chromatography. Research the others at the library and either a) write a report explaining how they work or b) do an investigation using one of the other types of chromatography.
3. What is zone electrophoresis? Build the necessary apparatus and use it to do an investigation of plant pigments.
4. Make chromatograms from leaves of a variety of plants. How are they different and how alike?

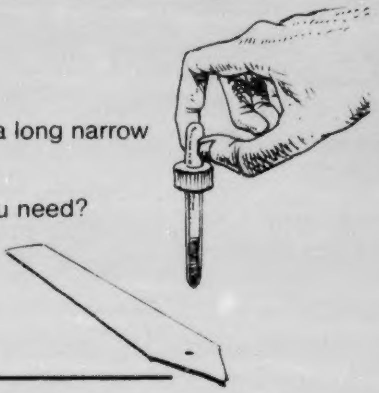
Chromatography

This activity will help you to become familiar with an analytical technique chemists call chromatography.

To do this activity, you need these materials. Please check to be sure you have them.

- ☐ filter paper
- ☐ marking pen with black water-base ink. You will share this with other groups of students.
- ☐ scissors
- ☐ small paper clip
- ☐ test tube with a cork, or a long narrow jar with a lid

Do you have everything you need?



Procedure

Step One: Cut a strip of filter paper just wide enough to fit inside the jar without touching the sides. Try to avoid getting a lot of greasy fingerprints on the strip of paper you will use.

Step Two: Force the small paper clip into the middle of the cork and use it to hang the strip of paper in the middle of the tube. If you cannot insert the clip in the cork, bend the clip over the side of the test tube. If your jar has a metal lid, you will need to punch a hole in it to support the clip. Attach one end of the strip of paper to the clip.

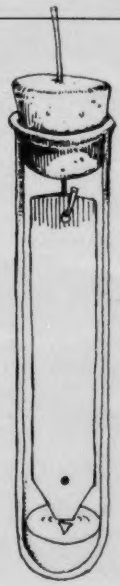
Step Three: Trim the free end of the paper into the form of a V, leaving the strip just long enough for the point of the V to almost touch the bottom of the test tube or jar.

Step Four: With the marking pen, place a spot of ink about 2 cm up from the bottom of the strip of paper (the V-shaped end). Place the spot in the middle. Let it dry.

Step Five: Place about 1 cm of water in the bottom of the tube.

Step Six: Hang the strip in the tube so that the paper touches the water but the ink spot is above the level of the water.

Step Seven: Observe what happens. Remove the strip from the jar or tube when the water has nearly reached the top of the paper.



Questions

From your observations, answer these questions on a separate sheet of paper.
1. Did the ink move, and if so why?
2. Why did we need the water? What did it do?
3. Why did we need the paper? What did it do?
4. Do you think the ink is made out of just one chemical substance or is it a mixture of several different substances. What evidence do you have?
5. The word "chromatography" comes from the Greek words *chroma*, meaning color, and *graphein*, meaning to write. Why do you think this name was chosen for this technique?

Chromatography of Chlorophyll

In this activity, we will try to use the technique of chromatography to separate the coloring matter from green leaves into different substances. One of these substances will be chlorophyll.

To do this investigation, you will need:

spinach leaves

coarse wet-or-dry sandpaper, two sheets

Ditto® fluid, a small amount

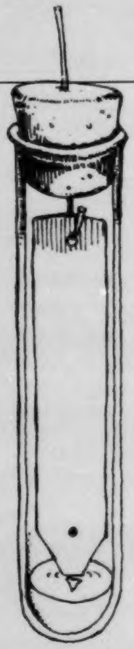
small jar

tooth picks

filter paper

test tube or long skinny jar, with a cork

paper clip



Procedure

Step One: Choose a couple of leaves and remove and discard the biggest veins and fibers. Grind the leaves between the two pieces of sandpaper. We are doing this to break down the cells in the leaves, so grind hard and long.

Step Two: Place the ground-up leaves and all remnants of the leaves into the small jar.

Step Three: Add just enough Ditto® fluid to cover the leaf material. Try to leave the concoction as concentrated as possible.
Stir with a toothpick. The liquid should turn green as pigment is dissolved from the ground leaves. (It helps if the Ditto® fluid is warmed in a hot water bath. Never do this near an open flame.)

Step Four: Cut a strip of filter paper just wide enough to fit inside the test tube or narrow jar without touching the sides, and just long enough to reach to the bottom of the tube. Trim the bottom of the strip to make a V-shape. Fasten the other end to the cork. Check that it fits the test tube properly.

Step Five: Use a toothpick to put a drop of the green liquid about 2 cm up from the bottom of the V at the end of the filter paper. Place the drop in the middle of the paper. Let it dry, then repeat the process, putting the new drop on exactly the same place as the old.

Step Six: Pour about 1 cm of Ditto® fluid into the test tube, just enough to cover the tip of the filter paper.

Step Seven: Hang the filter paper in the tube, being careful that the spot is above the level of the fluid.

Step Eight: Observe what happens. Remove the filter paper from the test tube when the Ditto® fluid has nearly reached the top of the paper. Examine the paper strip carefully. What you have made is called a **chromatogram**.

Questions

Answer the following questions on a separate sheet of paper.
1. Did the spot of green liquid remain in the same location after the filter paper was placed in the fluid? Describe what happened.
2. Do you have more than one color band on your chromatogram?
3. What evidence do you have that the leaf you studied contained more than one pigment?
4. Describe each color you find on the chromatogram and how many millimeters it is from the tip of the V.
5. Can you think of any reasons why some molecules might be moved farther by the solvent than others? What?

Detecting the Products of Photosynthesis: Starch

Note: Iodine, a poisonous substance, is used in this lesson.

Objectives

This lesson introduces the idea of using an indicator to detect the presence of a chemical compound, in this case, an iodine solution to detect starch. We then use this technique to see if the production of starch in leaves is related to light energy. The concepts developed are:

The parts of plants we choose to eat are usually those in which food energy has been stored.

Light energy is essential for the production of carbohydrates in green plants.

Format of the Lesson

Review of forms of chemical energy in food

Discussion of technique of using indicators

Student investigation of foods, using iodine indicator

Preparation of plant

(Several days are required for changes to occur in the leaves.)

Analysis of leaves and discussion

Materials Needed

indicator tincture of iodine from the medicine cabinet works fine. The laboratory version, called Lugol's Solution, is prepared by dissolving 10 gm of potassium iodide in 100 mL of distilled water; then adding 5 gm of iodine. This solution can be stored in dropper bottles and is ready for use. Note that, like tincture of iodine, it is poisonous and should not be put in the hands of unsupervised young students.

medicine dropper

paper towels

familiar foods, such as bread, potato, rice, banana, noodles, sugar, carrot, and others as available. Be sure to get some that do not contain starch (such as refined sugar). Only a very small amount is needed; usually it can be salvaged from the school cafeteria.

potted plant such as a geranium

hot plate

aluminum foil

Pyrex® beakers one large and one small

worksheet **Iodine, a Starch Detector.** One per student.

activity sheet **Starch and Light.** One per group.

Reviewing the Forms of Chemical Energy in Food

We eat food for several different purposes. Some foods provide materials our body needs, like vitamins or the essential amino acids. But other foods primarily provide energy. What sorts of foods are these? (ANS: the sugars and starches.) It may take some discussion to develop this point.

Where does the energy we get out of sugars and starches come from? (ANS: sunlight)

Reviewing our general photosynthesis equation,

$$CO_2 + H_2O \xrightarrow{\text{chlorophyll}} [CH_2O] + O_2$$

point out that the $[CH_2O]$ represents a part of a molecule. Sugars are produced as a result of photosynthesis, but these are often transformed into starches for storage.

Indicators

How can we discover whether there is starch in something? We can use an indicator. An indicator is a substance that indicates the presence of another substance, usually by changing color. Solutions containing iodine are used as indicators for starch. If starch is present, the spot where you place the iodine solution will change from reddish-brown to blue-black. If starch is not present, the reddish-brown color will remain. We will now investigate some common foods to find out if they contain starch.

Emphasize to the class that iodine is poisonous and will stain the fingers, if not handled properly. Food tested with iodine should not be eaten afterwards.

Divide the class into groups, if that is desired, and distribute the worksheet and materials, the iodine last.

Post-Activity Discussion

On the chalkboard, compile a list of foods in which the students detected starch, and another list of those in which no starch was found. Do results agree with our previous knowledge of the starch content of foods? Conclude that we have a reliable test for starch.

Starch and Light

Explain to the class that starch is a form in which plants store chemical energy, sometimes in their leaves. If the starch is the result of photosynthesis, then we should be able to find some relation between light and starch. We will do an investigation to see if that is so.

Have students cover one or two leaves of the plant with aluminum foil. Assign someone to care for the plant, being sure it receives adequate sunlight every day. Allow the plant to remain with a few leaves covered for three days. Then do the next activity.

Testing for Starch

This activity is possibly better done as a demonstration for the class, since hot liquids are needed to prepare the leaves. The student activity sheet can be run off so students can follow along with the procedures and record their observations.

Explain to the students that we are going to test the leaves of the plant for the presence of starch. However, the green color of chlorophyll would hide the color of the iodine test. So our first task must be to remove the chlorophyll.

Proceed with the activity following the steps outlined on the activity sheet.

Final Discussion

Ask the class why some leaves showed the presence of starch and others didn't. What does this indicate about the role of light in the production of food energy?

Iodine, a Starch Detector

Many plants store chemical energy in the form of starch. In this investigation, we will see how an iodine solution can be used to detect starch.

IODINE IS POISONOUS. IT WILL STAIN YOUR FINGERS IF IT GETS ON THEM. DO NOT EAT ANY FOOD TESTED WITH IODINE.

To do this investigation, you will need these supplies:

- ☐ foods known to contain starch
- ☐ foods that don't contain starch
- ☐ foods that may or may not contain starch (you're not sure)
- ☐ iodine solution
- ☐ medicine dropper
- ☐ paper towels

Do you have everything you need?

Procedure

Step One: Select the foods you will test. Take a very small piece of each one, and place the pieces on a paper towel.

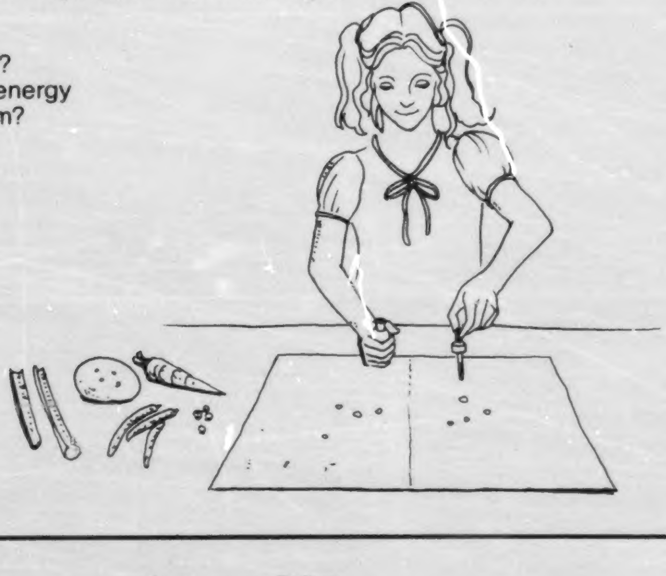
Step Two: Put a drop or two of the iodine solution on each sample. Then cap the bottle and put it away.

Step Three: Observe the color of the spot where the iodine was placed. If the color of the spot changes to blue-black, starch is present. Record your observations on the form provided, putting a + under Observations if starch is present, and a − if it isn't.

Food Tested	Observations

Questions to Answer on a Separate Sheet of Paper

1. Do foods contain starch?
2. Do all foods contain starch?
3. Where does the chemical energy stored in the starch come from?



Starch and Light

Is light necessary for the production of carbohydrates?

To do this investigation, you will need:

- ☐ leaves from a plant some of the leaves should have been completely covered by aluminim foil for the past three days. Keep careful track of which leaf was covered and which uncovered.
- ☐ hot plate
- ☐ aluminum foil
- ☐ iodine solution
- ☐ Pyrex beakers, one large and one small
- ☐ alcohol or Ditto® fluid

Do you have everything you need?

Procedure

Step One: Boil some water in a large beaker. In a smaller beaker, warm some alcohol. Caution: never use an open flame to do this. Provide adequate ventilation.

Step Two: Take one of the leaves that was *not covered* and place it in the boiling water for about two minutes.

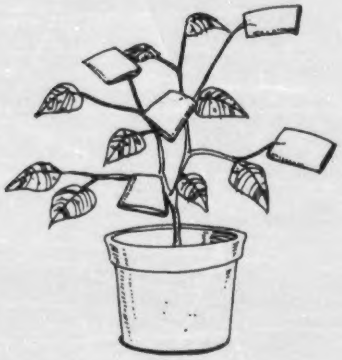
Step Three: Remove the leaf from the water and place it in the warm alcohol for a few minutes. The green color from the leaf will come out into the alcohol.

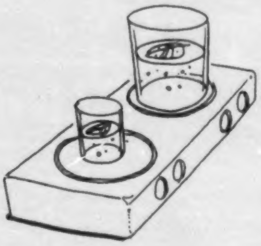
Step Four: Remove the leaf from the alcohol and rinse in water. Place it on a paper towel to dry.

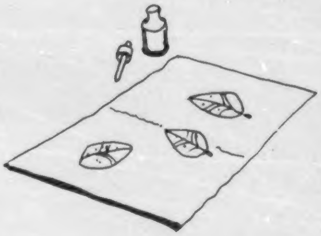
Step Five: Repeat Steps Two through Four with a leaf that *has* been covered for the last three days.

Step Six: Place several drops of iodine solution on each of the two leaves. After a few minutes, note any change of color.

Step Seven: Put all materials and supplies back where they belong.







Questions

1. Does either of the leaves appear to contain starch? Which, and how do you know?
2. What substance did the alcohol appear to remove?
3. What form of energy appears to be essential to the production of starch in green plants?
4. Do you think there was starch in the covered leaf before we covered it? What do you think happened to the starch?

Detecting the Products of Photosynthesis: Oxygen

Objectives

This lesson contributes to developing the students' understanding of the following ideas.

Oxygen is a product of photosynthesis in plants.

The oxygen of our atmosphere was produced by green plants.

Format of the Lesson

Review photosynthesis equation

Focus on oxygen and its importance to us

Introduce *Elodea*

Student assembly of apparatus

Observation

Introducing a variable: sun, shade, dark (three days may be necessary for results)

Demonstrate presence of oxygen in tube

CONDUCTING THE LESSON

Materials Needed

Elodea or anacharis plant. Available at most aquarium shops for around 50¢ a bunch.

jar or beaker, about 1-liter capacity.

funnel made of glass or clear plastic, small enough to fit into the above jar. Check local housewares departments and hardware stores. If funnels must be ordered, a good choice is a powder funnel of polymethylpentene, Nalgene catalog #4253-0080, $16.44 per dozen.

test tube to fit over end of funnel.

water must be chlorine-free. The chlorine can be removed from tap water by drawing a sufficient quantity a day or two in advance, and letting it sit. To do this, you may want to collect some gallon jugs.

lamp if sunlight is not available, a light strong enough to support photosynthesis in the plants must be provided. Fluorescent plant lights are ideal.

cardboard boxes big enough to cover the jars with test tubes inserted.

splint or a match tied to the end of a length of coat hanger wire, used after the flame has died out.

activity sheet **Is Oxygen Produced During Photosynthesis,** one per group.

worksheet **Evidence of Oxygen,** one per student.

Review Photosynthesis Equation

Go over the general equation

$$CO_2 + H_2O \xrightarrow{\text{Chlorophyll}} [CH_2O] + O_2$$

for photosynthesis. Review the meaning of each term. The equation says oxygen will be released. Is it?

Focus on Oxygen

What is oxygen? Is oxygen important to us? Elicit students' knowledge of oxygen and its importance.

Introduce *Elodea*

Show the students a piece of *Elodea*. Ask what it is. (ANS: A plant, a green plant, a water plant.) Confirm that it is a green plant that grows in fresh water, and is often grown in aquariums. We will use it to investigate whether oxygen is produced as a result of photosynthesis. This is fitting because most photosynthesis on our planet takes place in green plants living in water: some estimate that 90% of all photosynthesis on earth takes place in microscopic ocean-dwelling plants.

Arrange the class in groups and pass out the worksheets and materials. Place a drawing of the completed setup on the chalkboard (see activity sheet). Ask the class whether the plant in the drawing would be able to get water? How? Would it be able to get carbon dioxide? How? Then ask the class to put together the apparatus as explained in the worksheets.

The First Twenty Minutes' Observations

Bubbles of oxygen may soon be noticeable on the green leaves, if plants are healthy and there's enough light. These bubbles will rise to be trapped in the upper part of the test tube, and are oxygen released during the process of photosynthesis.

Introducing a Variable

After observing the production of bubbles, we'll want to test whether the production of this gas is really related to the light. To do that, we will vary the amount of light, and see if that varies the amount of gas.

Divide the setups into three groups. Have one-third of the students leave their setups in direct sunlight; another third leave theirs in a shady place; and the last third cover theirs with the cardboard boxes. Continue observing for several days, entering the observations on the record sheets.

Note that the observations need not be simple. For example, do bubbles appear all over the leaves, or only in certain spots? if sunlight is falling on only a portion of a leaf, do bubbles appear all over the leaf? How far from the sun/shadow boundary?

What Is the Gas?

When enough gas has been collected in a tube, you can test the gas by thrusting a glowing splint (or a glowing match) into the tube. The greater proportion of oxygen in the tube will cause the splint to burst into flame.

Comparing the tubes from plants that received differing amounts of sunlight should reveal that the more sunlight, the more oxygen. This tends to indicate that the plant needs light to produce oxygen.

Projects for Independent Investigation

1. Design another experiment to test the substance in the test tube to see if it really is oxygen.
2. Can you think of a way of performing this investigation with another water plant? With a land plant?

Is Oxygen Produced During Photosynthesis?

To do this investigation you will need the following materials:

- ☐ *Elodea* or anacharis plant
- ☐ jar or beaker that holds about a liter of water
- ☐ small funnel made of glass or clear plastic
- ☐ test tube
- ☐ water (you cannot use water directly from the faucet because it contains chlorine, which will harm the plant — get special water from your teacher)
- ☐ light source, either direct sunlight or a plant light
- ☐ worksheet, **Evidence of Oxygen**

Do you have everything you need?

Procedure

Step One: Fill the jar about half full of water.

Step Two: Place a 7- to 10-cm piece of *Elodea* plant in the jar. Put the funnel over it, as shown in the drawing.

Step Three: Fill a test tube full of water from the jar. Seal it with a finger or thumb; turn the tube upside down and put its top under the surface of the water in the jar. Carefully place the tube over the small open end of the funnel without letting any air in. Then take your finger off. If you accidentally let a bubble in, try again.

Step Four: Place the apparatus in bright sunlight. If sunlight is not available, place it under a bright lamp.

Step Five: Observe what happens for about twenty minutes. Record your observations on the sheet your teacher gives you.

Step Six: Your teacher will put you into one of three groups.

One group will leave its plants in direct sunlight.

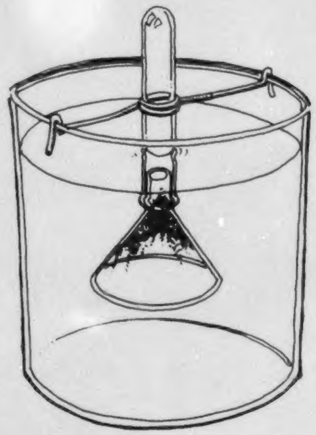
One group will leave its plants in the shade.

One group will keep its plants in complete darkness under cardboard boxes.

Find out what group you are in. Following your teacher's directions, put your plant in the right condition for your group.

Step Seven: Continue observing the plants for three days. Record your observations on the sheet your teacher gave you.

Step Eight: Disassemble the apparatus. Put the materials back where they belong.



Evidence of Oxygen

1. Observations during the first half hour:

Describe any evidence you detect of the production of gas.

2. Circle the conditions under which you are to keep your plant:

direct sunlight   shade   darkness

Record your observations below:

TIME	CONDITION OF LEAVES	CONDITION OF TEST TUBE
after 30 minutes		
after one day		
after two days		
after three days		

3. Do you think light is necessary for the plant to produce gas? Describe observations to support your opinion.

4. What do you think the gas in the tube is? Describe any tests or observations that support your opinion.

Respiration: Running Photosynthesis Backwards

Objectives

This lesson contributes to students' understanding of the following ideas:

The energy in food substances is released by breaking down those substances into simpler substances.

Plants as well as animals depend on the energy captured by photosynthesis.

Format of the Lesson

Discussion of photosynthesis

Demonstration of carbon dioxide in breath

Discussion of energy needs of plants

Experiment to determine whether heat and carbon dioxide given off by germinating seeds

Materials Needed

For the Carbon Dioxide Experiment:

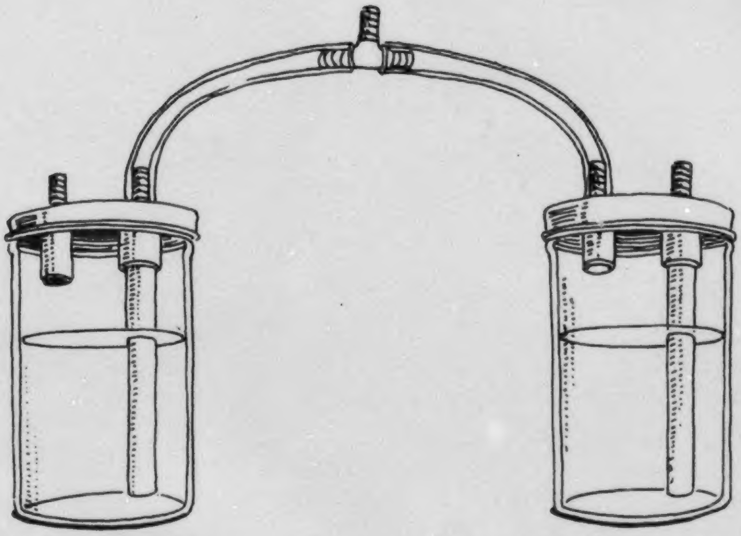
limewater, enough to fill as many bottles as you have available for the demonstration of carbon dioxide in exhaled breath. Limewater is made by putting either calcium oxide (lime) or calcium hydroxide (hydrated lime) in water. Calcium oxide is available in some building supply, garden, and hardware stores; otherwise either chemical may be obtained from many drugstores. Lime is corrosive and evolves heat when mixed with water.

(Question — what do you think the source of this energy is?)

To prepare a large quantity of limewater, fit a large bottle with a siphon. Add water, then at least 10 grams of lime or hydrated lime per liter of water. Stir or shake. Allow to sit capped and undisturbed for a day, then siphon off the clear liquid into a tightly capped bottle. (Capping is important because we want to keep carbon dioxide in the air from reaching this solution until we are ready to use it.)

When carbon dioxide is bubbled through a limewater solution, a milky precipitate of calcium carbonate is formed. This is the commonest test for carbon dioxide.

$Ca[OH]_2 + CO_2 \rightarrow CaCO_3 + H_2O$



If you're in a well-equipped science classroom, you can quickly make a setup like that illustrated out of flasks, two-hole rubber stoppers, glass tubing, and rubber tubing. If you don't have such equipment, adurable alternative which can be saved for other experiments and later years can be made from plastic pipe fittings. Anyone who can make ¾ inch holes in a metal lid can do this; perhaps you can get a parent handyman to help. (A page of instructions for a volunteer is provided.) For **one** apparatus, you will need the following materials:

jars two identical jars such as two-pound peanut butter jars, or large mayonnaise jars. The rubber seals in the lids should be intact. Eventually they will fail; the lids can be saved by cutting a new seal from gasket material.

plastic tubing ½-inch inner diameter, about two running feet. This diameter is large enough to permit easy breathing. About 55¢ a foot from hardware stores.

T-connector one, ½" size, plastic. Hardware and plumbing supply stores have these and the other plastic plumbing items described below. About 50¢.

½-inch hose barb to male ½-inch pipe fitting four, plastic. About 50¢ each.

plastic pipe connector 4, ½-inch female thread to slip. About 18¢ each. These are used as nuts to hold the hose barb fitting to the jar lid.

steel washers ¾-inch inner diameter, 4. About 18¢ each.

plastic pipe ½-inch, two pieces about 5 inches long, depending on the dimensions of your glass jars.

glue to cement plastic pipe to fittings. Although special cement is available, for our purposes Duco cement or similar types can be used.

For the seed respiration experiment:

test tubes or narrow bottles such as an Alkaseltzer® bottle.

cotton balls

thermometers with celsius scale

bromothymol blue solution (see note on page XX).

bean or corn seeds that have been soaked overnight.

bean or corn seeds dry

test tube holders or clay.

activity sheet **Seed Respiration** one per group.

Conducting the Lesson

Beginning Discussion

Item by item, solicit from the class the various "ingredients" in the simplified photosynthesis formula, and write in on the chalkboard or overhead, like this:

$$6CO_2 + 6H_2O + \text{energy} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Review the meaning of the formula: we start with carbon dioxide and water, and use energy to rearrange those atoms into a molecule of carbohydrate and a molecule of water.

Erase "energy," the arrow, and the chlorophyll. Replace the arrow with one pointing in the other direction.

$$6CO_2 + 6H_2O + \qquad - C_6H_{12}O_6 + 6O_2$$

Ask the class if they think we could run this process backwards? What is missing on the left? What else would we get?

Write in "energy" again on the left side of the arrow.

Detecting Water

In addition to energy, the chemical equation predicts we would get water and carbon dioxide. Can we tell if our bodies are making water from carbohydrates? Do we give off water? How? (ANS: yes, through sweat, urine, and as humidity in breath.)

Where does this water come from? Do we take in water? Is there water in the food we eat? How can we tell if the water we give off comes from respiration?

It's unlikely that your students will be able to think of an experiment to show whether the water they give off comes entirely from the water they eat and drink or if some is made from the sugars their bodies are "burning" up. (But scientists can in the laboratory, using radioactive tracers, and some of the water in your body does come from your food.)

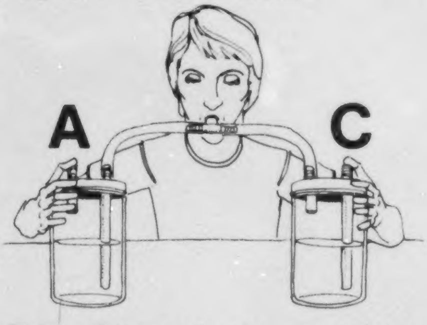
Detecting Carbon Dioxide

How about carbon dioxide? If we are running photosynthesis in reverse we must be giving out more carbon dioxide than we take in. How can we prove this?

An increase in carbon dioxide in exhaled breath can be demonstrated in several ways. One way is to compare room air with exhaled breath by pumping room air through some limewater, and exhaling through a straw into another container of limewater. The limewater in the container through which the exhaled breath is assed will turn milky faster than the limewater in the other container. However, it is difficult to be sure the same volume of gas has been passed through both solutions.

A more elegant experiment takes room air, passes it through limewater to remove all carbon dioxide (and to indicate how much was in the air) and then passes it through the lungs and into a second, identical container.

1. Put a thumb over tube C. Inhale.
2. Open C. Close A. Exhale



This activity can be done as a demonstration, if you don't have multiple sets of the apparatus. The solution in the jar receiving the exhaled breath will turn milky much faster than that in the jar receiving straight room air. In discussion with the students, draw out how this shows that the person breathing into the tube is giving off carbon dioxide.

Detecting Energy

That leaves the third item on the left side of our equation.

How about energy? Are you putting out energy? How can you be sure?

(Some possible student answers: because I'm moving. Because I'm warmer than the air around me, and I'm not being heated by any radiation.)

Summary

So that's where our bodies get their energy. From respiration — running photosynthesis backwards. (Incidentally, biologists use the term respiration to refer to what goes on in cells, changing sugars to energy, water and CO_2; what we call breathing they call external respiration.)

Plant Respiration

Do plants also need to respire? How do you know? (ANS: They grow and carry on other life activities that use energy.)

Plants respire continuously as animals do. In the sunlight, they are usually producing carbohydrates through photosynthesis faster than they are "burning up" carbohydrates by respiration.

Are the green parts of plants the only parts that need energy? Do plants need energy at night? Where do plants store energy?

Let's think about seeds, for example.

Do seeds need energy? For what?

Do seeds have green leaves?

Where do seeds get their energy?

Why are seeds such a large part of our diet? (Wheat, rice, oats, etc.)

How could we see whether seeds respire? (ANS: We could detect carbon dioxide. We could detect heat.) Let's try to do that.

Ask the students to recall how we used bromothymol blue in an earlier experiment to detect carbon dioxide. (If you did not do this experiment, tell the class that when carbon dioxide is bubbled through water, it makes a very weak acid. Bromothymol blue is a chemical that is blue in a basic solution but yellow in an acid solution.)

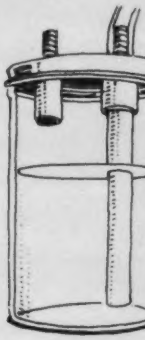
Pass out the activity worksheets and the materials.

Projects for Independent Investigation

1. Germinate some seeds and see how many days it takes before they can make food on their own by the process of photosynthesis.
2. Design an experiment that would show that plants give off carbon dioxide during respiration.
3. Dissect some seeds. What parts do you think are mainly for storage of food energy?
4. Do chicken eggs need a store of energy? What part of the egg stores the energy? Can you design an experiment to prove that fertile chicken eggs breathe?

Making Two-Inlet Lids

We need some airtight bottles with lids that have two tubes coming through them. One of the tubes should go almost to the bottom of the jar and the other just into the jar, like this:



Tools and Skills Needed

To make this equipment, you need to be able to cut ¾ holes in thin sheet metal, and you need to be able to glue plastic pipe fittings together.

Materials

To make one set of two jars:

2 jars Two identical jars such as two-pound peanut butter jars or large mayonnaise jars. The rubber seals in the lids should be intact.

4 ½-inch hose barbs to male ½-inch pipe fitting, plastic

4 plastic pipe connectors ½-inch female thread to slip. These are used as nuts to hold the hose barb fitting to the jar lid.

4 steel washers ¾-inch inner diameter.

plastic pipe ½-inch, two pieces about 5 inches long, depending on the dimensions of your glass jars.

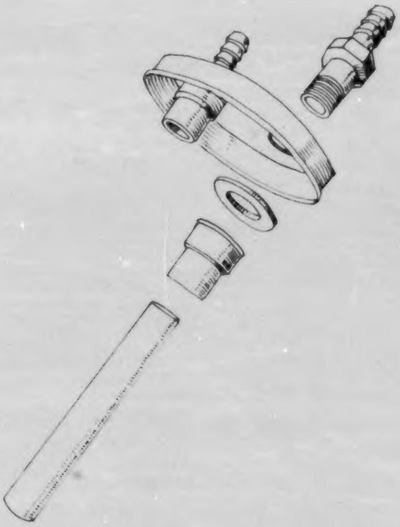
glue to cement plastic pipe to fittings. Although special cement is available, for our purposes Duco cement or similar types can be used.

Assembly

Lay the two ¾-inch washers on the inside of the lid, touching each other but not touching the rubber seal on the lid. Trace the holes.

Cut out the holes by drilling, filing, using a hand grinder, or whatever way you think is best.

Assemble the hose barbs, washers, and connectors as shown in the drawing, using the connectors as nuts. The joint should be as gas-tight as possible.



Cut two pieces of plastic pipe to fit the connector, so that when the lid is screwed onto the jar the pipe will just clear the bottom of the jar. In each jar, glue one of these pieces into a connector.

Please leave the jars open so that the fumes from the glue will have a chance to escape before the students use the jars.

Thank you very much! The equipment you've made will be useful to us for years.

We have already planned a lesson using this equipment, so we need the jars by

______________________, 19______.

Seed Respiration

Seeds contain carbohydrates produced by green plants through the process of photosynthesis. This stored food (chemical energy), which originated with the sun, releases its energy when it combines with oxygen. The release of this energy with the production of carbon dioxide and water is called **respiration.**

In the activity, you will try to find evidence to show that the seed is giving off carbon dioxide and energy.

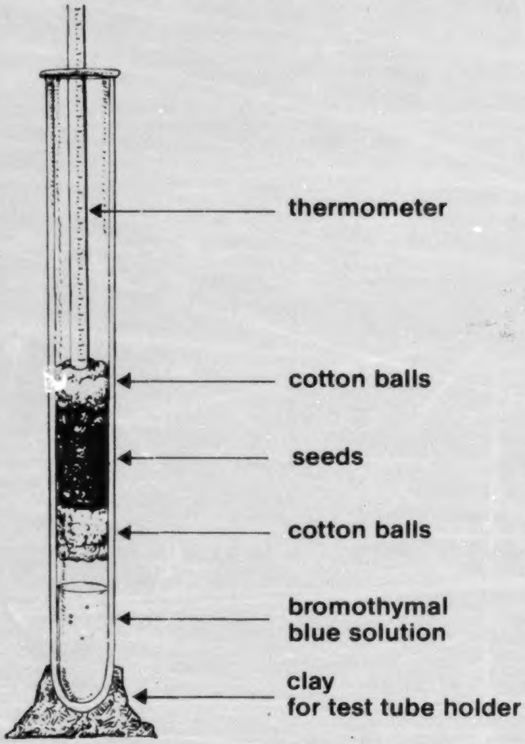
☐ two test tubes or narrow bottles

☐ cotton balls

☐ two thermometers

☐ bromothymol blue solution

☐ bean or corn seeds, some that have been soaked overnight and have started to sprout, and some that are dry and are not germinating.



Step One: Set up the jars or test tubes as shown in the drawing. Pour about an inch of bromothymol blue solution into the bottom of each tube. The bromothymol blue solution should be yellow, if it is not, ask your teacher to add a few drops of sodium hydroxide solution.

Step Two: Stuff cotton balls into the tube to make a plug for the seeds to rest on. The cotton should be above the bromothymol blue solution; it should not get wet.

Step Three: Place the soaked seeds in one test tube an the dry seeds in the other tube. In the middle of the seeds, place a thermometer. Use another layer of cotton as plugs around the thermometers.

Step Four: Observe what happens and make a record of your observations. Let the tubes stand overnight and repeat your observations.

Is the Carbon Dioxide We Exhale the Result of Energy Use?

Objectives

This lesson contributes to students' understanding of the following ideas:

The carbon dioxide we exhale is the result of respiration.

We get our energy from the food we eat.

Format of the Lesson

Discuss rate of respiration

Set up experiment

Do first experiment

Enter results

Exercise

Repeat titration

Compare with body weights

Materials Needed

pint bottles or 250-mL flasks, one for each student.

straws box of straws with the smallest diameter you can find. Each student needs four.

eyedroppers one per student. It is possible to buy 500 eyedroppers for 9¢ each.

graduated cylinder (10 mL) ideally, one per student. Student quality cylinders (e.g., Fisher 8-549-2B) are about two for $6.12. Borrow from the high school lab. If you cannot get enough cylinders, do this portion of the investigation in groups.

graduated cylinder (100 mL) one per four students. Student quality cylinders are about two for $8.58 from supply houses, but you can probably borrow these from the high school lab.

sodium hydroxide solution (0.4%) one bottle per two students. To prepare, dissolve 4 grams of sodium hydroxide in 996 mL of water. Use caution; heat will be liberated. The resulting solution is quite dilute. (You may wish to ask a high school chemistry teacher to prepare this for you.)

phenolphthalein solution, 0.5% in small bottles with their own droppers, about one bottle for ten students. Again, get the help of the high school chemistry teacher. If these droppers are physically different from the droppers used for the NaOH solution, it helps to prevent confusion. Twenty-five grams of phenolphthalein costs about $3.50, but it's unlikely you'll have to buy it.

Teacher Background

In this activity, we use a procedure chemists call **titration.** Phenolphthalein is used as an indicator — a substance that can show visually whether another substance is present, or, in this case, how acidic a solution is. When the solution containing the phenolphthalein is acid, the phenolphthalein is colorless. When the basic (or alkaline) the phenolphthalein is pink. In the activity, we first make the solution just slightly basic, so the indicator is pink. Adding CO_2 makes the solution acidic, and therefore colorless. By adding a base, sodium hydroxide, we remove the acidity and make the solution basic again. We can tell when this happens because the color changes to pink again. HOW MUCH BASE WE HAVE TO ADD TO MAKE THE SOLUTION PINK AGAIN TELLS US HOW MUCH ACID THERE WAS IN THE WATER, AND THAT TELLS US HOW MUCH CARBON DIOXIDE WAS IN THE EXHALED AIR.

Preliminary Discussion

Review the previous experiments that have demonstrated that people and seeds produce carbon dioxide. We know, for example, that germinating seeds produce carbon dioxide and non-germinating ones don't.

Another way we could relate carbon dioxide to energy use is to see whether the more energy an animal uses, the more carbon dioxide it produces.

We will try that with us.

Pass out the materials and worksheet. Give some thought in advance to where the exercise is to take place and what form it is to take. Going out and running around the track is ideal.

After the Experiment

Ask how many of the class found their rate of carbon dioxide production was greater after exercise. How many times greater?

Is there a sex-linked difference between the metabolic rate of boys and girls? (To study this question, one first has to eliminate the variable of body weight, which can be done by calculating the mL of NaOH solution used per pound of body weight. Care should be taken to avoid making this a source of embarrassment to students who may be sensitive about their weight. Do this by asking students to calculate mL per pound without asking them to reveal their weight.)

Projects for Independent Investigation

1. How fast does the rate of carbon dioxide output build up and then taper off when we start exercising and then stop? Devise a way of taking a continuous series of, say, one minute samples of a person starting to exercise and then stopping. Show the class a graph of your results.
2. By using a normal solution of NaOH, it is possible to figure out how many molecules of sugar would have had to have been "burnt" to produce the exhaled carbon dioxide. Perhaps with the help of a chemistry teacher, revise the experiment to determine sugar burnt instead of mL of NaOH solution.
3. How does a doctor determine a patient's metabolic rate? Why? Perhaps a student who has had a basal metabolism test could describe it to the class.

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How Fast Am I Burning Fuel?

You need the following tools and supplies. Please check to be sure you have them.

☐ graduated cylinder, 10 ml

☐ graduated cylinder, 100 ml

☐ eyedropper

☐ indicator solution, phenolphthalein

☐ water

☐ NaOH 0.4% solution

☐ straws, 4

☐ pint bottle or 250-mL flask

Do you have everything you need?

Procedure

Step One: Take the eyedropper and count how many drops of water it takes to make a milliliter of water in the 10-mL cylinder. Use this eyedropper for the rest of the investigation.

Step Two: Measure out exactly 100 ml of water into the bottle or flask. Add four drops of the phenolphthalein solution.

Step Three: Add a drop of the NaOH base. Swirl the water around in the bottle without spilling it. Does the water turn pink? If not, add one more drop. Swirl. Pink? If not, add another drop. Continue until the solution in the bottle turns pink and stays pink. You have now made the solution basic (the opposite of acidic).

Step Four: Relax. Be lazy. Pinch your nose closed. Through two straws, bubble all the air you exhale through the pink solution for exactly one minute. The solution will lose its pink color, because the carbon dioxide you're exhaling is creating a weak acid in the solution.

Step Five: Now we're going to measure how much carbon dioxide you exhaled, by measuring how much base (the NaOH solution) we have to add to make the solution pink again.

Add NaOH solution drop by drop, swirling after every drop, just as you did before. Carefully count the number of drops used.

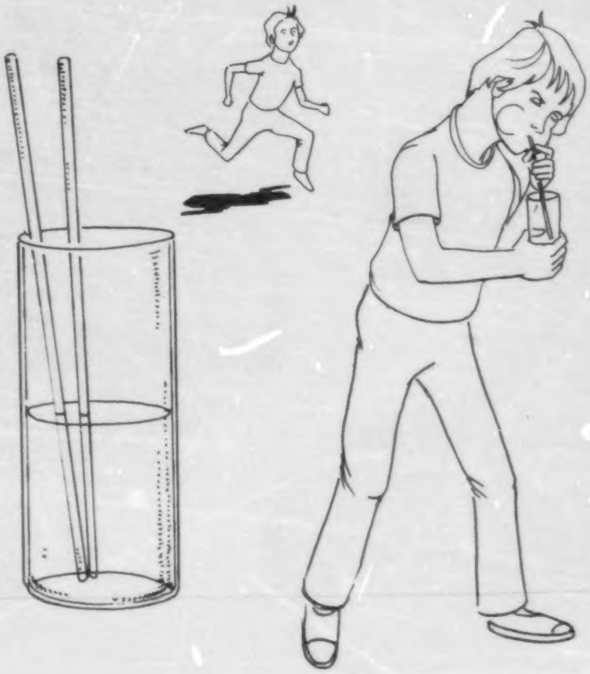
Record the number of drops used, and convert it to milliliters.

Step Six: Wash out your bottle and prepare a new bottle just as you did in Step Three.

Step Seven: Exercise hard for five minutes. Run in place or outside. Don't stop until you get back to your flask. Exhale through the solution in the flask for exactly one minute.

Step Eight: Repeat Step Five.

Step Nine: Put all the materials and supplies away.



Observing Carbon Dioxide

Do you produce more carbon dioxide when you are exercising than you do when you are resting? The measurements you make during this activity will help you answer this question.

I. Calibrate Your Dropper

_______ drops is equal to one milliliter.

II. Resting

How many drops of NaOH solution were needed to turn the solution pink again? _______ drops

Using the conversion factor you worked out in section 1, calculate how many milliliters of NaOH solution you added.

_______ mL of NaOH

(Optional) If you wish, divide the number of drops by your body weight in pounds

$$\frac{\text{body weight in pounds}}{\text{drops of NaOH}} = \_\_\_\_\_\_\_ \text{ drops per pound}$$

III. After Exercising

How many drops of NaOH solution were needed to turn the solution pink again?

_______ drops, which is equal to _______ mL of NaOH

(Optional) If you wish, divide the number of drops by your body weight in pounds

$$\frac{\text{body weight in pounds}}{\text{drops in NaOH}} = \_\_\_\_\_\_\_ \text{ drops per pound}$$

III. Do you produce more carbon dioxide after exercising than you did before? How can you prove it?

IV. (Optional) Do bigger students produce more carbon dioxide? Give reasons that might explain your result.

Measuring Food Energy

Objectives

This lesson contributes to developing the students' understanding of the following ideas.

Food contains stored chemical energy.

The chemical energy stored in food can be converted to heat by oxidizing the food (combining it with oxygen).

We can measure the amount of energy stored in food.

Vocabulary

small calorie
food Calorie
calorimeter
milliliter
gram

Format of the Lesson

Review by discussion the role of sunlight in growth of plants, and of plant materials in life of animals

Discuss the calorie as a unit of measurement

Divide the class into groups

Pass out the worksheets

Release the materials and conduct the experiment

Discuss results

Assign homework

Materials Needed

wire coat hanger one for each group.

aluminum beverage can 8 ounce size (compacts). One per group.

aluminum foil about 30-cm-long piece per group.

modeling clay

straight pins one per group.

peanuts one per group in shells.

thermometer graduated in degrees Celsius, one per group.

pliers several pairs.

matches

water

calorimeter one prepared in advance as an example.

(*scale* accurate to .01 gm, optional.)

miniature marshmallows one bag

activity sheet **A Nutty Way to Measure Calories.**

worksheet **Peanut Calorie Calculations.**

Teacher Background

Most people are familiar with the calorie tables used by people who are trying to lose weight. These tables give the energy content of various foods, as measured in Calories (capital C). Unfortunately, there is a very messy and confusing distinction between Calories and calories. A calorie, as we learned in Unit One is the amount of heat needed to raise the temperature of one gram of water one degree Celsius (to be strictly accurate, at 15°C). A food Calorie (capital C and also sometimes called a kilocalorie) is one thousand small calories, or the amount of heat needed to raise one kilogram of water one degree Celsius.

To measure the number of calories in a sample of food, it is burnt and the heat produced is measured. Usually, this is done in a special apparatus called a calorimeter. Obviously, the calorimeters we make in this experiment will not give accurate results. They do adequately illustrate the concept, and the activity reinforces the students' recognition that the energy of sunlight has been stored in the food.

For Discussion Before The Experiment

Establish through discussion a consensus among the students that there must be energy stored in food. Review that it gets there through photosynthesis.

Set a problem: Do all foods have the same amount of energy? Does a pound of hamburger provide the same amount of energy as a pound of cheese?

How can we measure the amount of energy stored in a piece of food?

Students may have a variety of suggestions: e.g., feed it to animals and make them work, etc.

Discuss the suggestions and point out that, whatever method we decide to use to measure the energy, the first thing we need is a unit of measurement.

Establishing a Unit of Measurement

Write "calorie" on the board.

(For students who have done the activities in Unit One, this will be a review.)

Define calorie: the amount of energy needed to raise the temperature of one gram of water one degree Celsius.

One gram of water has a volume of almost exactly one milliliter.

Define food Calories as one thousand small calories.

So, to measure the calories in food, we have to use those calories to warm some water.

Respiration Outside the Body?

The purpose of this short discussion is to convince students that burning a food provides the same amount of energy as the process of respiration would.

Write the equation for respiration on the board.

$[C\ H_2O] + O_2 \rightarrow CO_2 + H_2O +$ energy

What's happening? What is combining with what? Do you know any other chemical reactions where things combine with oxygen? (ANS: Burning, rusting.)

Suppose we took some carbohydrate — write $C_6H_{12}O_6$ on the board — and burn it. What would we end up with? (ANS: Water and carbon dioxide.) Write out the chemical equation. It's the same as respiration! Since we start with the same things, and end up with the same things, the amount of energy we get out must be the same, too.

To Weigh or Not to Weigh? —for Your Information Only

A more precise way of conducting this experiment is to weigh a peanut before and after burning it. It then becomes possible to calculate a calories per gram value for peanuts and, in addition, you don't have to burn all of the peanut. If you have a balance available and the students are sufficiently proficient, this is a better way to do the experiment. Ditto off a sheet with blocks in which students can record their results.

We've assumed you don't have a balance and you want to keep the activity as simple as possible. In this case, the peanut has to be burned to ashes and, unfortunately, this can be a bit time-consuming.

Setting Up the Experiment

Be sure all students are able to read their Celsius thermometers.

Show the prepared model of the calorimeter.

Divide the class into groups and arrange seating appropriately.

Distribute worksheets and materials.

After the Experiment

Calculating calories

On the chalkboard, put the formula:

calories = (rise in temperature in degrees Celsius) times (grams of water)

Have each group of students calculate the number of calories produced by burning their peanut. Convert to food Calories (kilocalories).

If you think your class would benefit from repeating the experiment, have them compare the food energy in a peanut and a pecan.

Sources of Error

How accurate do you think the measurement is?

What might be some sources of error?

Did all of the heat produced by the burning peanut go into the water?

Why must the water we start with be room temperature? Suppose the water were colder than room temperature, what would happen during the experiment? In which direction would our results be off? What would happen if the water were warmer than room temperature?

Do you think our measurement is too high or too low?

When scientists use a more precise apparatus to measure the calorie content of peanuts, they get a value of about 5.59 Calories per gram of peanut. (A typical peanut weighs about one gram.) On the basis of your results and the way you got them, does it seem to you that 5.59 Calories per gram might be a more accurate value?

Homework Assignment

Make a record of all the food you eat for two days. From a Calorie chart, determine how many Calories were in each item eaten. How many Calories per day are you eating?

Thanks to Brother Tom Heinle, whose experiments showed using a can gives better results than using a test tube, and to Gene Chiapetta, for suggesting extensions that improved the motivation for the activity.

Peanut Calorie Calculation

Amount of water used = ______________ milliliters = ______________ grams.

Temperature of water in °C before burning peanut = ______________ °C.

Temperature of water after burning peanut = ______________ °C.

Difference in temperature = ______________ degrees.

calories = (mass of water in grams) x (temperature change in °C)

An example

Ten grams of water are heated 15°C.

calories = (10 grams of water) x (15°C)

calories = 150 calories

Use the above formula and your measurements to calculate how many calories of heat were obtained from the peanut.

calories = ______________ grams x ______________ °C

calories = ______________ calories

This calculation is in small calories. There are a thousand calories in a food Calorie, or large Calorie. To convert calories to Calories, divide the number of small calories by 1000.

large calories = $\frac{\text{small calories}}{1000}$

Example:

Calories = $\frac{\text{150 calories}}{1000}$

Calories = 0.15 Calories

How many food Calories did burning the peanut add to the water?

Calorie = $\frac{\text{calorie}}{1000}$

Calories = $\frac{\text{\_\_\_\_\_\_\_\_}}{1000}$

A Nutty Way to Measure Calories

Does eating a peanut give us more energy than eating a miniature marshmallow? You can find out by measuring the number of calories of food energy in each. A calorie is the amount of heat needed to raise the temperature of one gram of water one degree Celsius. One gram of water has a volume of one milliliter.

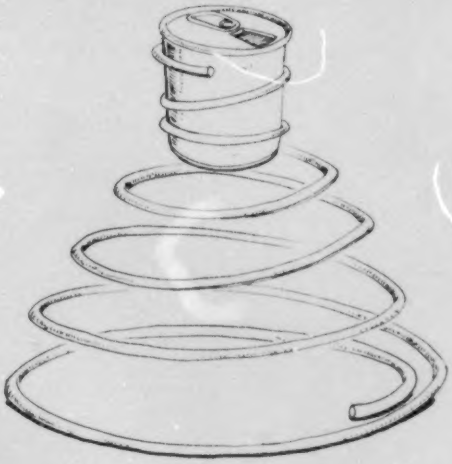
To find out how many calories are stored in the peanut, we will burn it and use the heat produced to warm some water. Then, knowing how many grams of water were warmed and how many degrees the temperature of the water rose, we can calculate the calories.

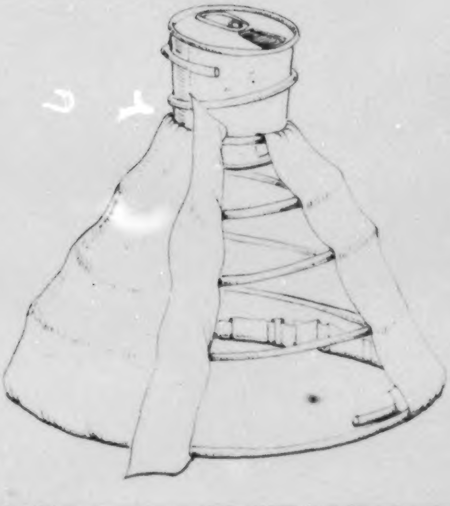
Check to see if you have all the materials you need.

☐ one wire coat hanger
☐ one aluminum can
☐ aluminum foil
☐ clay
☐ straight pins
☐ peanuts, mini-marshmallows
☐ pliers
☐ graduated cylinder
☐ Celsius thermometer
☐ matches
☐ water

Procedure

Step One: Untwist the coat hanger to get a heavy wire. Wrap the wire around the can in the shape of a spiral. Make the lower turns of the spiral bigger, gradually increasing the size so it makes a base. The diameter of the base should be about 8 to 10 cm.



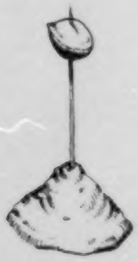


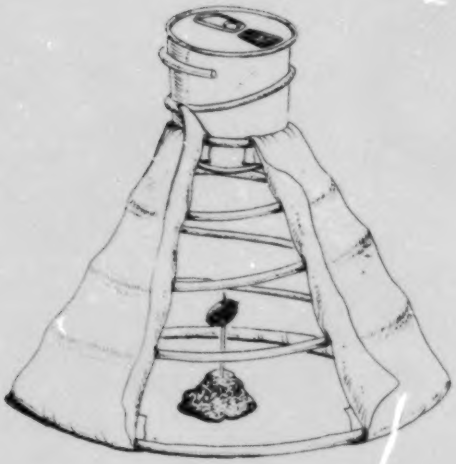
Step Two: Cover the spiral of wire with aluminum foil. Leave an opening for a door.

Step Three: Measure 100 milliliters of water and place it in the can. What is the mass of 100 milliliters of water?

Take the temperature of the water. Record your measurement on the worksheet.

Step Four: Embed the head of a pin in a hunk of clay. Place a shelled peanut on the point.





Light the peanut with a match. As soon as it starts to burn on its own, place it under the can in the calorimeter, and allow it to burn.

If the peanut sputters and goes out before it looks all burnt up, get a new peanut and fresh water, and start over.

When the peanut looks all burnt up and goes out, take the temperature of the water again. Record the temperature on your worksheet.

Step Five: Calculate the calories.

Step Six: Repeat the procedure with a marshmallow.

Step Seven: Clean up. Put all the materials back where they belong.

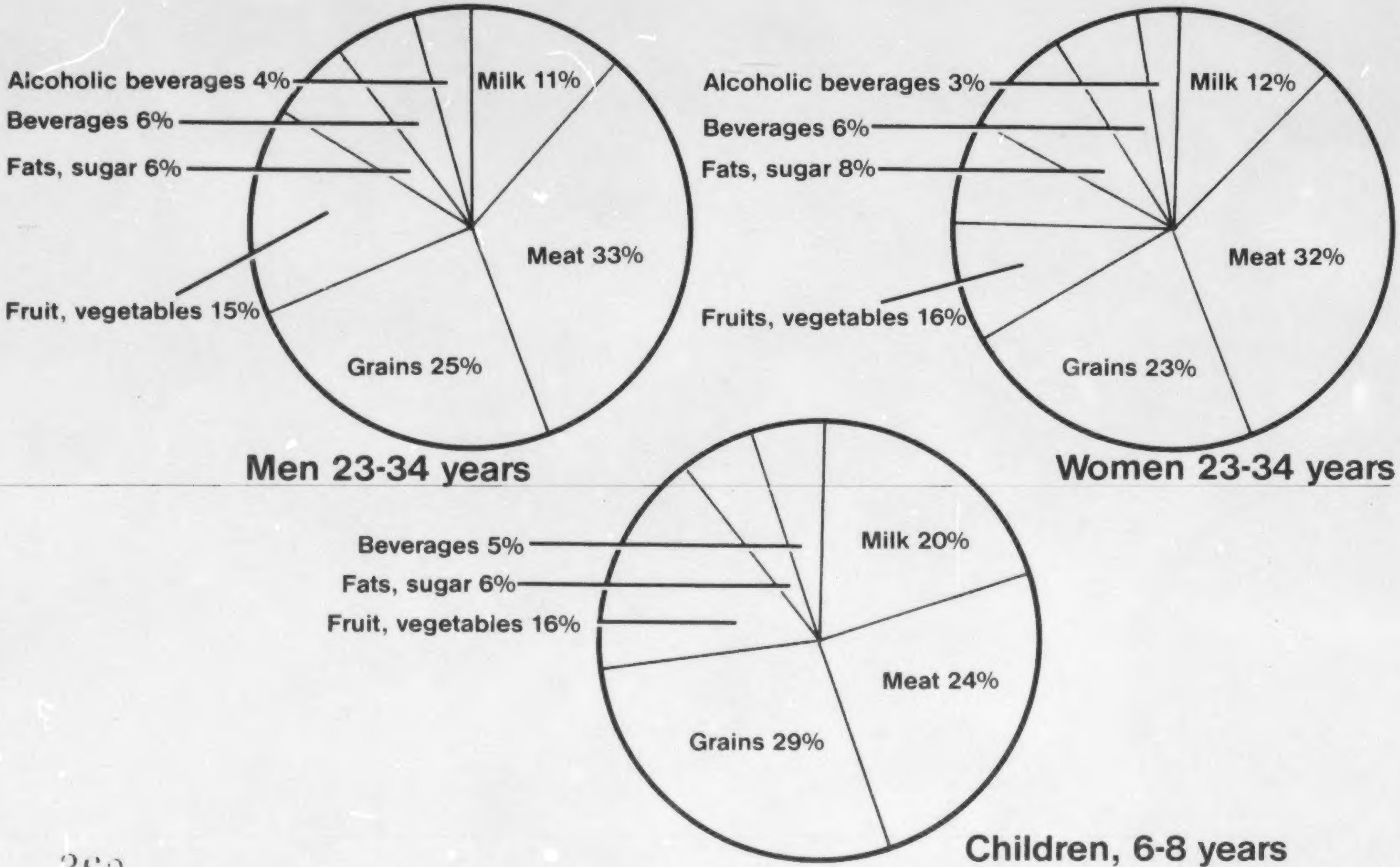
Tracing Your Own Food Chain Backwards

Here are some things we eat. Find out what's in them and follow their food energy back to green plants. If you're not sure, guess. One example is done for you.

food	ingredients	animals along the way	green plants
birthday cake	flour		wheat
	sugar		sugar cane, sugar beets
	eggs	hen	wheat, corn
	milk	cow	grass, corn, hay
	butter	cow	grass, corn, hay
	salt		no food energy
	baking powder		no food energy

Now you do a hamburger, a breakfast cereal, and two foods you choose. Use more paper if you need.

Where People Got their Food Energy on One Day in Spring



Men 23-34 years

Women 23-34 years

Children, 6-8 years

Source: USDA Nationwide Food Consumption Survey, 48 States, spring 1977; preliminary.

Bumblebees and Energy

Some of the ideas on the hive economy of bumblebees came into sharper focus during a set of observations made by Tracy Allen, Sydney Cameron, Ron McGinley, and myself (1978) on a large colony of *B. vosnesenskii** near Berkeley. We made an analysis of the rate of food input to the colony, comparing it to the food reserves** and the worker force, in order to arrive at a measure of energy flow into and through various components of the colony.

We observed the traffic in and out of the colony for one whole day from 5:00 a.m. until 9:00 p.m. During that day we observed 1,932 bee foraging trips, and 958 of the returning workers carried pollen. On the next day, we sacrificed*** samples of bees entering and leaving the nest, weighing the pollen loads and dissecting out the honeycrops to measure volumes and concentrations of syrup carried out of and into the colony. The mean † amount of sugar carried by workers was 0.00021 g on leaving and 0.027 g on returning. The mean pollen load per worker was 0.021 g. On the basis of the total foraging trips per day, we calculated that the net daily sugar intake to the colony amounted to 45 g, while the daily pollen intake was 20 g (1).

Some of the workers had been individually marked with differently colored and numbered tags the day prior to the 16 hours of continuous observations. We could thus follow the foraging behavior of individuals. The marked workers spent most of their time in the field.

Foraging trips were usually one-half to one-and-one-half hours, and bees entering the nesthole in the ground usually reappeared in less than five minutes, even though the tunnel to the nest (which we later dug up) was nearly two meters long. Different bees were bringing in purple, gold, white, lemon-yellow, dark brown, gray, and sometimes, greenish pollen. The same individuals consistently brought back the same color pollen on consecutive trips. The colony as a whole was tapping the food resources from a wide variety of sources. However, it was not clear if the individuals specialized in different kinds of flowers or if they merely foraged in specific sites having different kinds of flowers (we will examine this question in detail in Chapter 8 through 10).

After determining the flow traffic and resources in and out of the colony, we dug up the nest and analyzed the contents. The colony contained 261 workers: one old, nearly bald, tattered queen (her baldness was probably due to a virus infection); 136 velvety new queens;

*a common species of bumblebee

**the honey and pollen stored in the hive

***when scientists have to kill an animal for research purposes, they say it has been "sacrificed"

average

1. Can you repeat the calculation?

From **Bumblebee Economics,** by Bernd Heinrich (pp 33-37). (Cambridge, MA: Harvard University Press, 1979.) Copyright © 1979 by the President and Fellows of Harvard College. Reproduced by permission.

392 queen pupae; 341 pupae of either drones or workers; 239 larvae; and about 50 eggs. The food stores (at midmorning) consisted of 5.7 g pollen and 260 g sugar, or 195 mL honey (other colonies we dug up contained almost no honey, but numerous full pollen pots.) Thus, the honey reserves amounted to six days of net input (2), and the pollen reserves to 0.3 days. (Incidentally, the honey tasted superb – we all agreed that it tasted superior to any honeybee honey we had ever tasted!) Pollen is important to maintain larval growth, but without sugar to provide energy, adult bees die within hours.

2. How did they calculate this?

If we assume that the food that the bees had accumulated represented an equilibrium*, then it is probable that most of the 50 g sugar and 20 g pollen brought into the colony per day by the worker force of fewer than 260 bees was eaten by the new queens and by queen and drone larvae. Without this drain, the worker force could have conceivably amassed considerable food stores. If honeybees could do as well, then a colony of 40,000 bees should accumulate nearly 15 liters of honey per day. Each bumblebee worker was averaging a net profit to the colony of at least 0.2 g sugar (about 0.3 mL honey) per day. Honeybees have almost no energy drain going to new queens, and only a small drain to drones. Their mode of creating new colonies – swarming – requires that resources be routed into food storage in late summer. (3) The stores are utilized to produce new workers in late winter, so that a single queen can leave the colony with a swarm to aid her in the early spring.

*that is, that they were eating each day about as much as they brought in, and the amount stored didn't change.

3. Can you think of other animals that do this?

A *B. vosnesenskii* queen weighs an average of 0.43 g, and a drone 0.1 g. If these bees have a pollen-to-bee conversion ratio similar to that observed for some other bees, then one gram of pollen should produce about one gram of adult bee biomass.* (However, additional pollen is eaten by bees soon after they emerge from the cocoon.) A forager returning with 0.021 g of pollen per load could supply enough pollen to produce one queen in twenty trips, or one drone in five trips. In the colony we observed, two workers that consistently collected pollen on every trip went on 9 trips per day, like most other workers. This adds up to 0.19 grams per pollen-forager per day under the conditions we observed. Therefore, slightly more than two forager-days would be sufficient to make one queen, and a little less than a day would be sufficient for a drone. The sugar needed for the development of a queen would be about 0.20 g. At 0.025 g sugar per forager-load, this requirement could be met in eight trips, also a day's effort. But since the bees generally collect both pollen and nectar on the same trip, often full loads of each, this does not constitute an additional foraging day.

*Takes 1 g of pollen to make 1 g of bee.

We can estimate the foraging effort that must have been mounted by the bumblebees in order to produce the cohort of reproductives found in the nest on June 8. At that time there were 1,160 adult and presumptive reproductives* in the nest, including 528 queens (136 adults, plus 392 queen pupae) and 630 drones (341 drone pupae, plus 239 larvae and 50 eggs). This represents a presumptive adult biomass of 290 g (528 x 0.43 = 630 x 0.1 g). At 0.21 g pollen per forager-day, about 1,380 bee-days of labor would be required to collect the pollen needed to rear the cohort of colony reproductives. These bee-days of labor could be supplied over a long time by a few bees, or over a few days by many. For example, if this labor were to be completed in 30 days (the average egg-to-adult development time), then only forty-six foraging specialists, or about one-sixth of the worker force, would be required. Generally, during the hours when a bumblebee colony is active, about one-third of the colony's population will be away from the nest foraging at any one time. How the bees allocate their labor and decide which tasks to perform is still unknown.

To summarize, the rapid and continuous operation of the bumblebee factory depends on a dependable supply of energy, and the sole source of energy is the sugar from nectar. As will be shown in Chapters 7 through 11, it is the worker's task to enhance energy flow into the colony by working skillfully and utilizing the best flowers available. Foraging optimization involves achieving the greatest foraging profit for the least cost. The primary energy costs are those of locomotion-shuttling to, from, and among the tiny energy-wells, the flowers.

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*young that would probably become fertile adults

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4. There are three energy inputs to the colony. Two are described here. Can you name all three?

5. The author mentions an unsolved problem. What is it? Can you think of any way to investigate that problem?

Transportation in the Food System

To do this project, you need a list of food. This list can be:

☐ a typical day's menu chosen by the class

☐ all the food you ate in one day

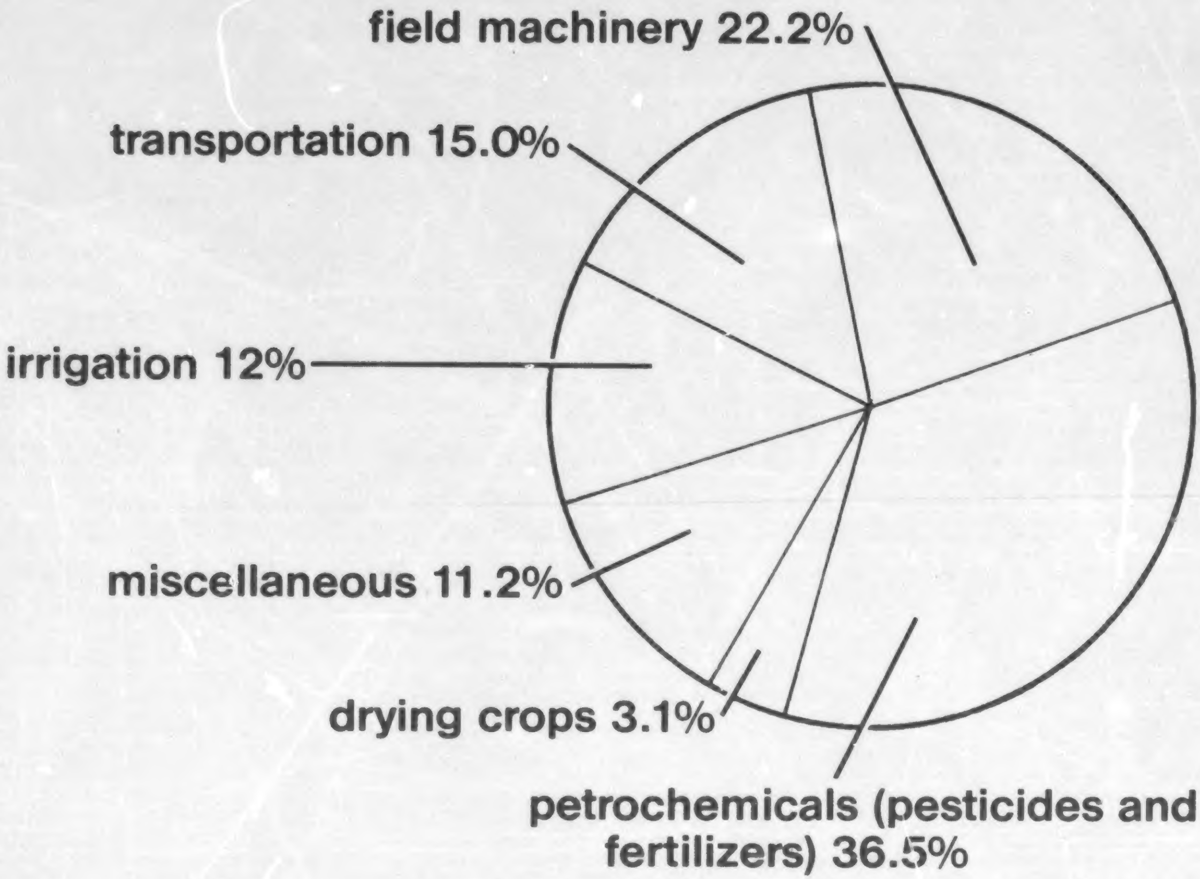
☐ all the food you family bought on one trip to the market

Put a check in the box that tells what kind of list you are using.

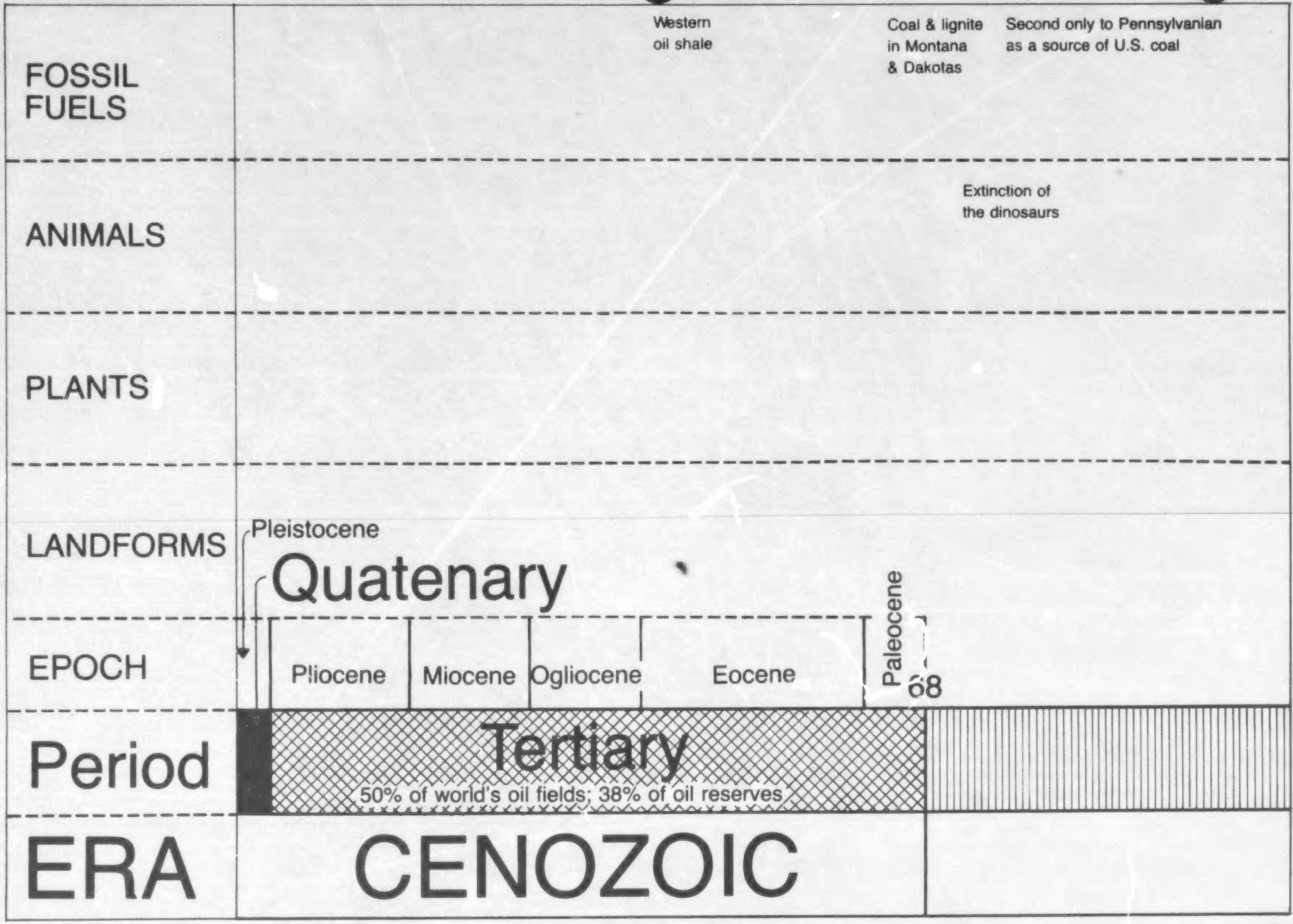
In the table below, write the name of a food and in the next column the name of the state or country it came from. (If you are not sure where it came from, study the packaging and make an educated guess. Be ready to explain the reasons for your guess.) Some examples are done for you.

orange juice	Florida
oatmeal	Minnesota
raisins	California

What is energy used for on the farm?

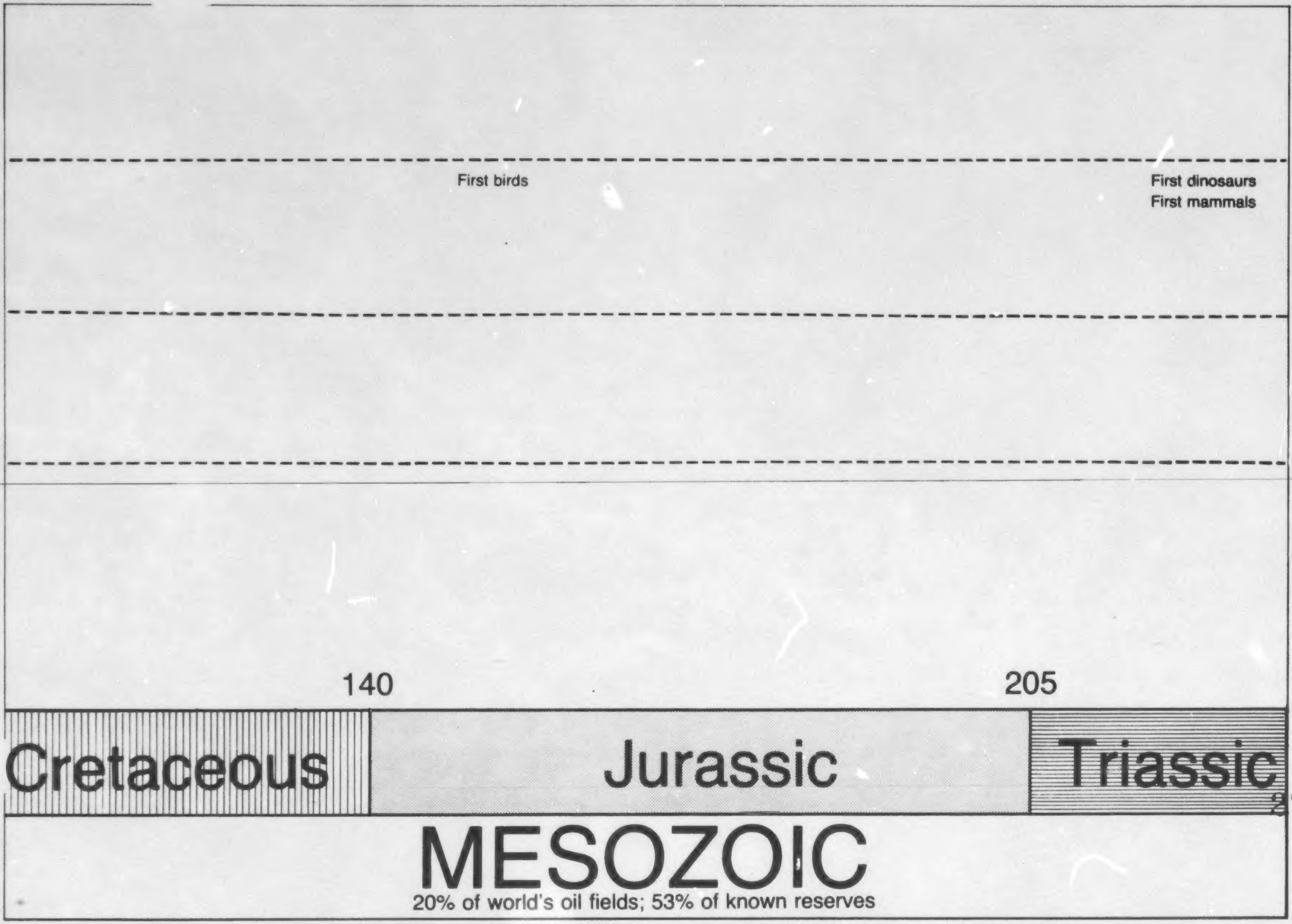


Source: 1980 preliminary data. **1981 Handbook of Agricultural Charts.** Agricultural Handbook No. 592. United States Department of Agriculture.


FOSSIL FUELS
Western oil shale
Coal & lignite in Montana & Dakotas
Second only to Pennsylvanian as a source of U.S. coal
ANIMALS
Extinction of the dinosaurs
PLANTS
LANDFORMS
Pleistocene
Quatenary
EPOCH
Pliocene
Miocene
Ogliocene
Eocene
Paleocene
68
Period
Tertiary
50% of world's oil fields; 38% of oil reserves
ERA
CENOZOIC

TAPE NEXT SHEET OVER THIS AREA

CUT ALONG THIS LINE



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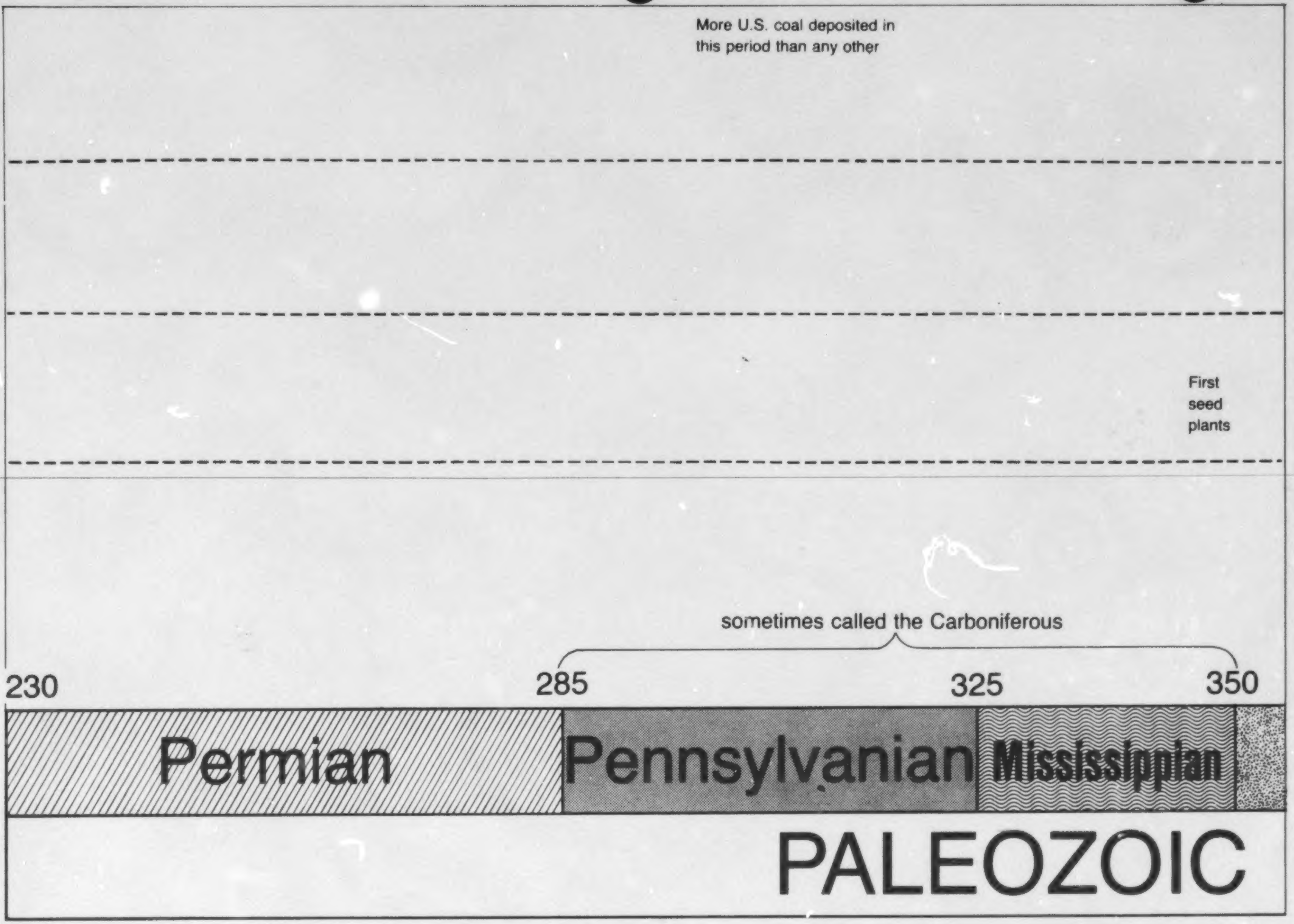

230
285
325
350
Permian
Pennsylvanian
Mississippian
PALEOZOIC

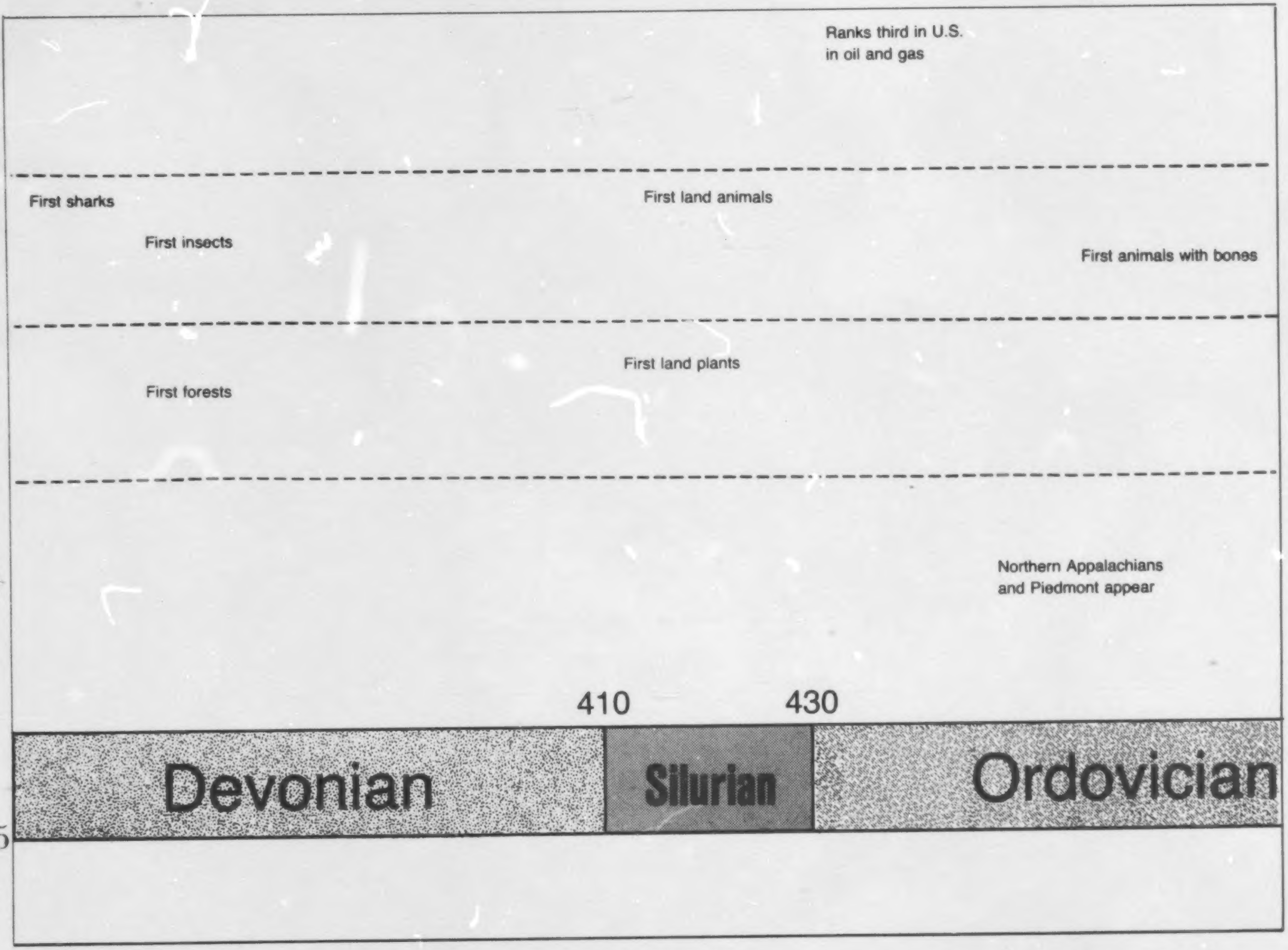
More U.S. coal deposited in this period than any other

First seed plants

sometimes called the Carboniferous

TAPE NEXT SHEET OVER THIS AREA

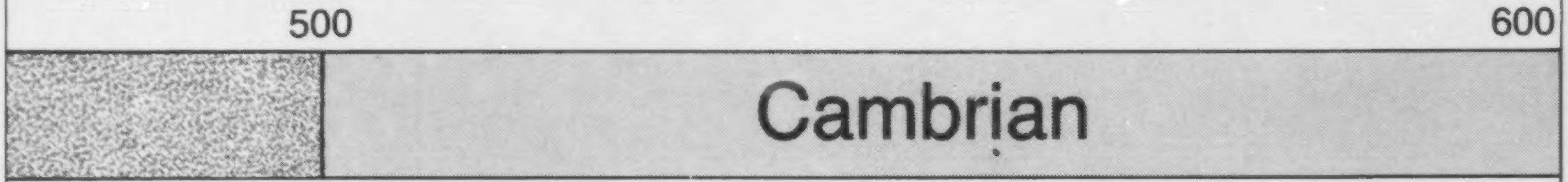
CUT ALONG THIS LINE


Ranks third in U.S.
in oil and gas
First sharks
First land animals
First insects
First animals with bones
First land plants
First forests
Northern Appalachians
and Piedmont appear
410
430
Devonian
Silurian
Ordovician

TAPE NEXT SHEET OVER THIS AREA

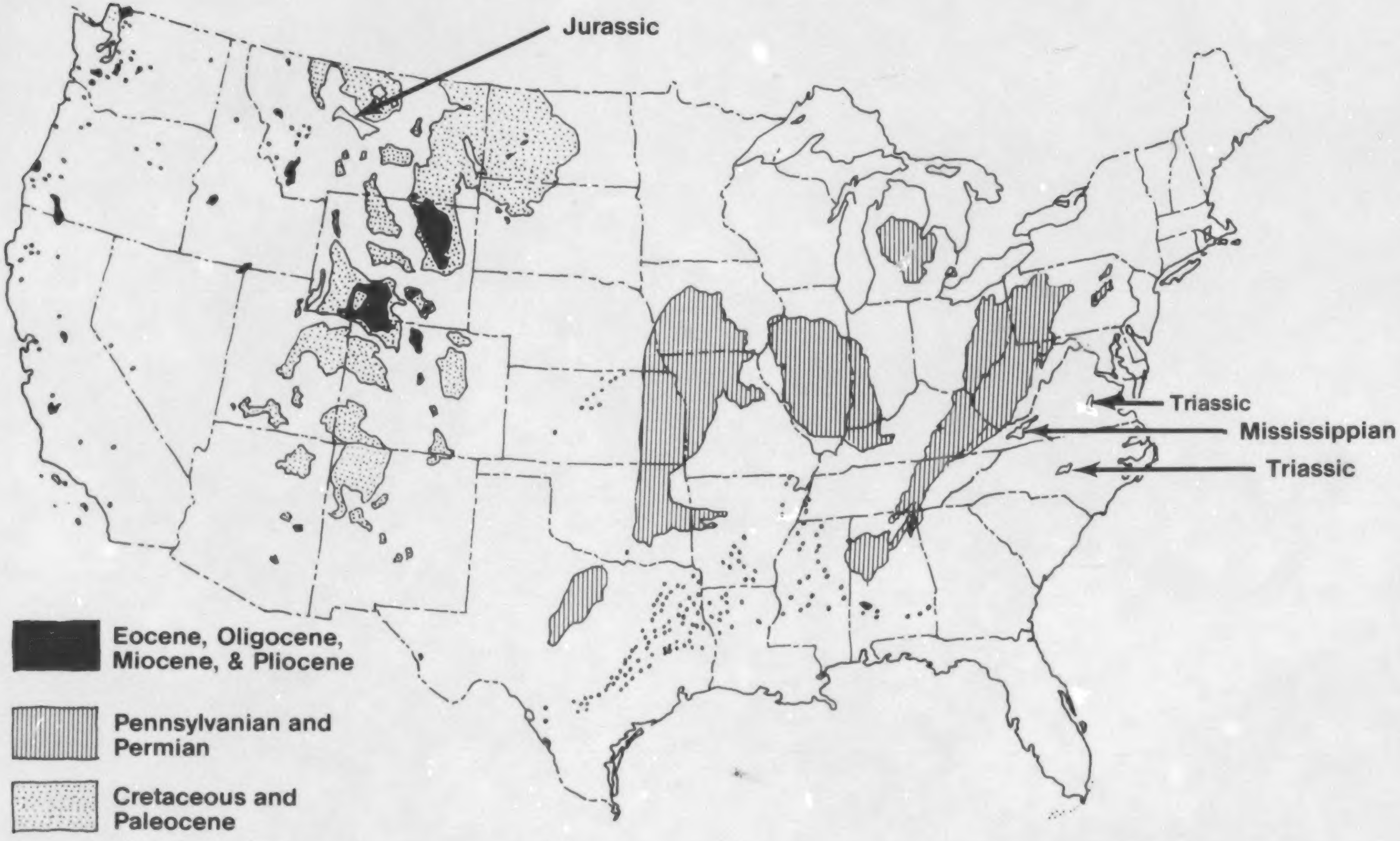
CUT ALONG THIS LINE

Many forms of
ocean life
appear

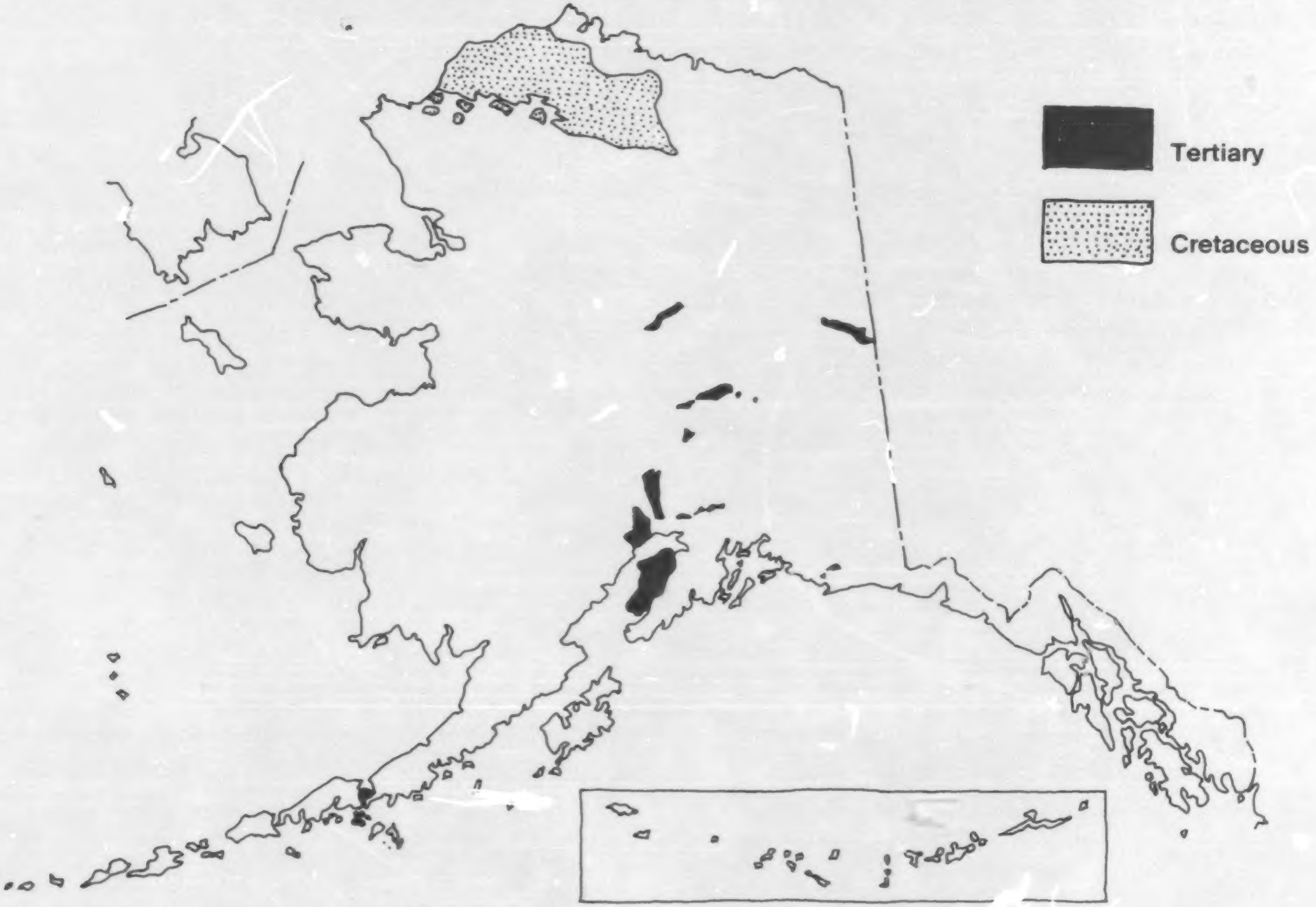

500
600
Cambrian

PRECAMBRIAN

When Were the Coals in the United States Living Plants?


Jurassic
Triassic
Mississippian
Triassic
Eocene, Oligocene, Miocene, & Pliocene
Pennsylvanian and Permian
Cretaceous and Paleocene

When Were the Coals in Alaska Living Plants?


■ Tertiary
▨ Cretaceous

Notes

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